Fast Beam Conditions Monitor as an Online Luminometer for CMS: Performance and Upgrade

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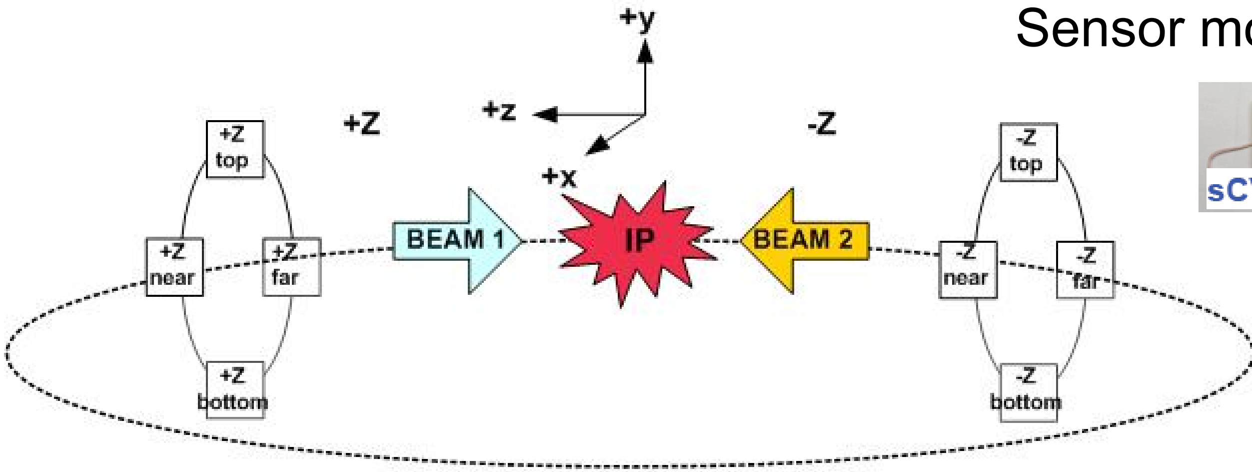
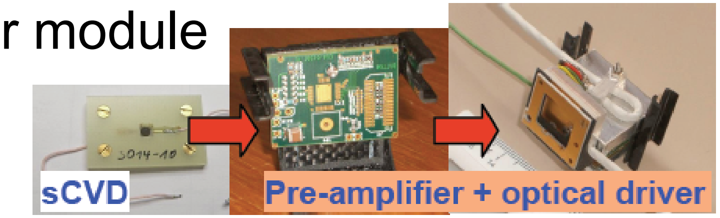
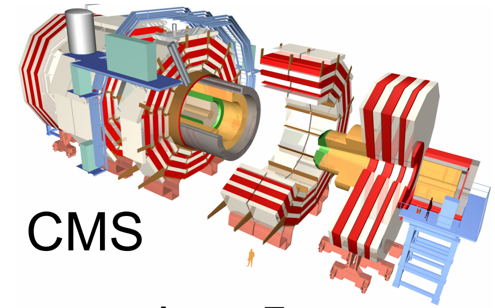
HSTD-9

Fast Beam Condition Monitor BCM1F



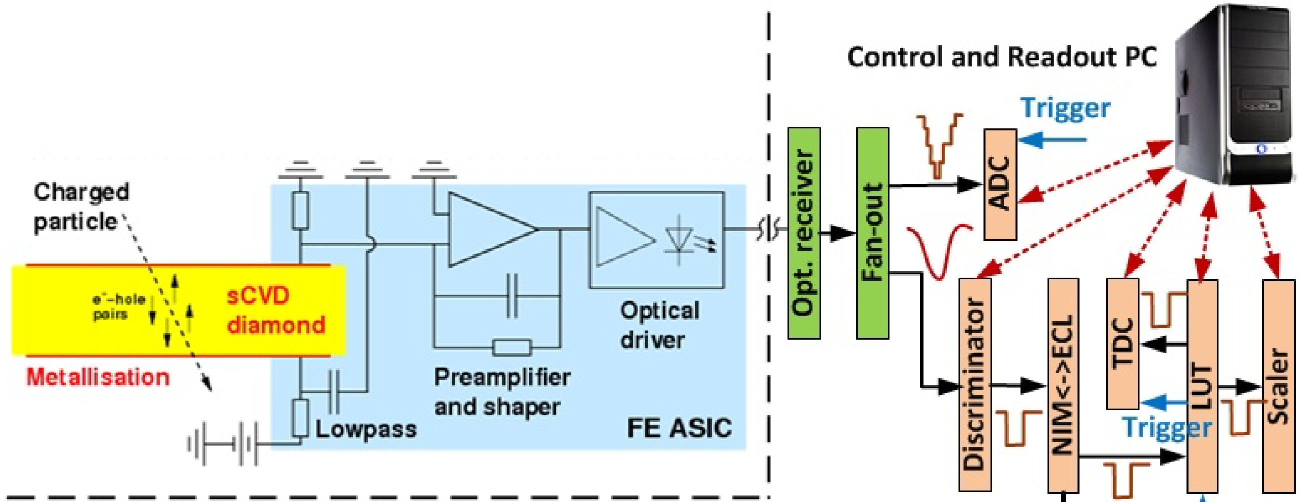
Sensor module

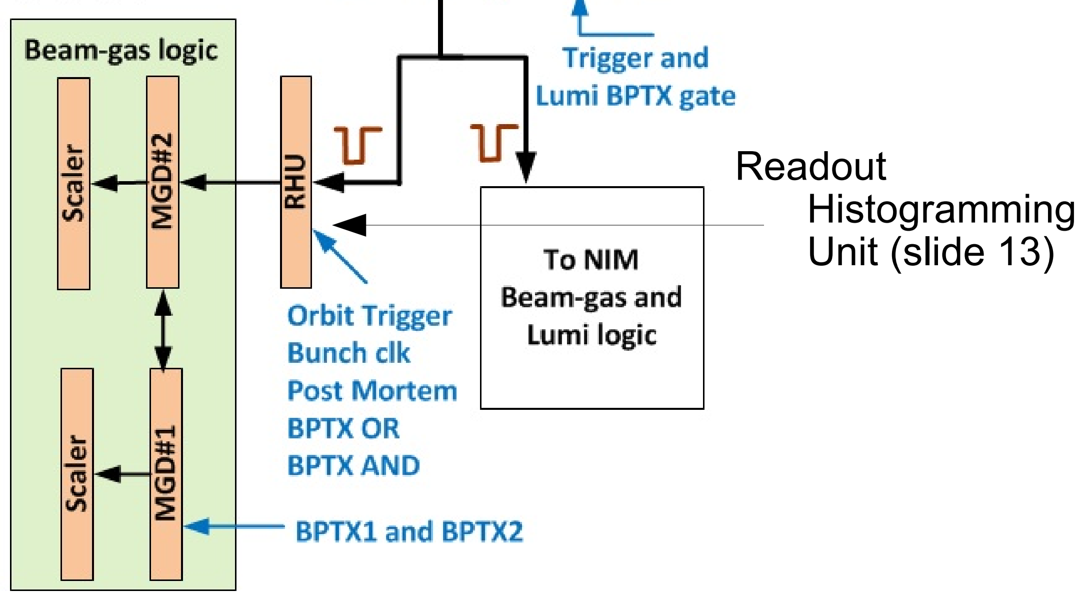


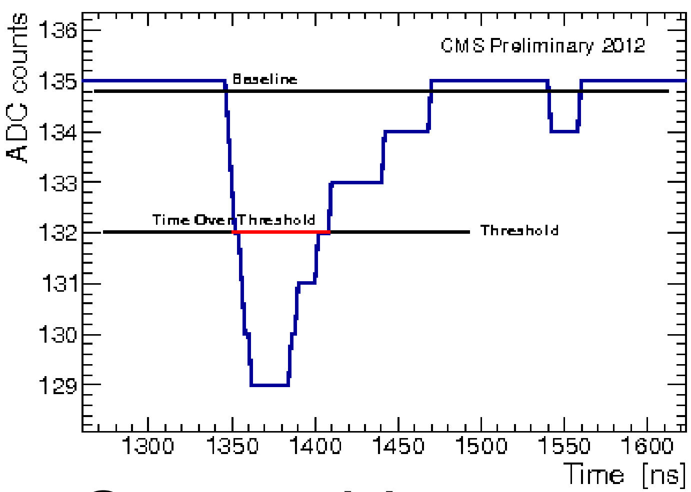


- 8 single-crystal CVD diamonds positioned around the beam-pipe, 5mm x 5mm, radial distance 4.5 cm, 1.8 m from interaction point
  - Diamond → no cooling, robust, radiation-hard
  - Sensor module: diamond, radiation-hard preamplifier, optical driver
- Bunch-by-bunch information on flux of beam halo and collision products
  - Monitor condition of beam: ensure low radiation for silicon tracker
  - **Calculate luminosity**
- Readout independent of CMS DAQ

BCM1F Electronics

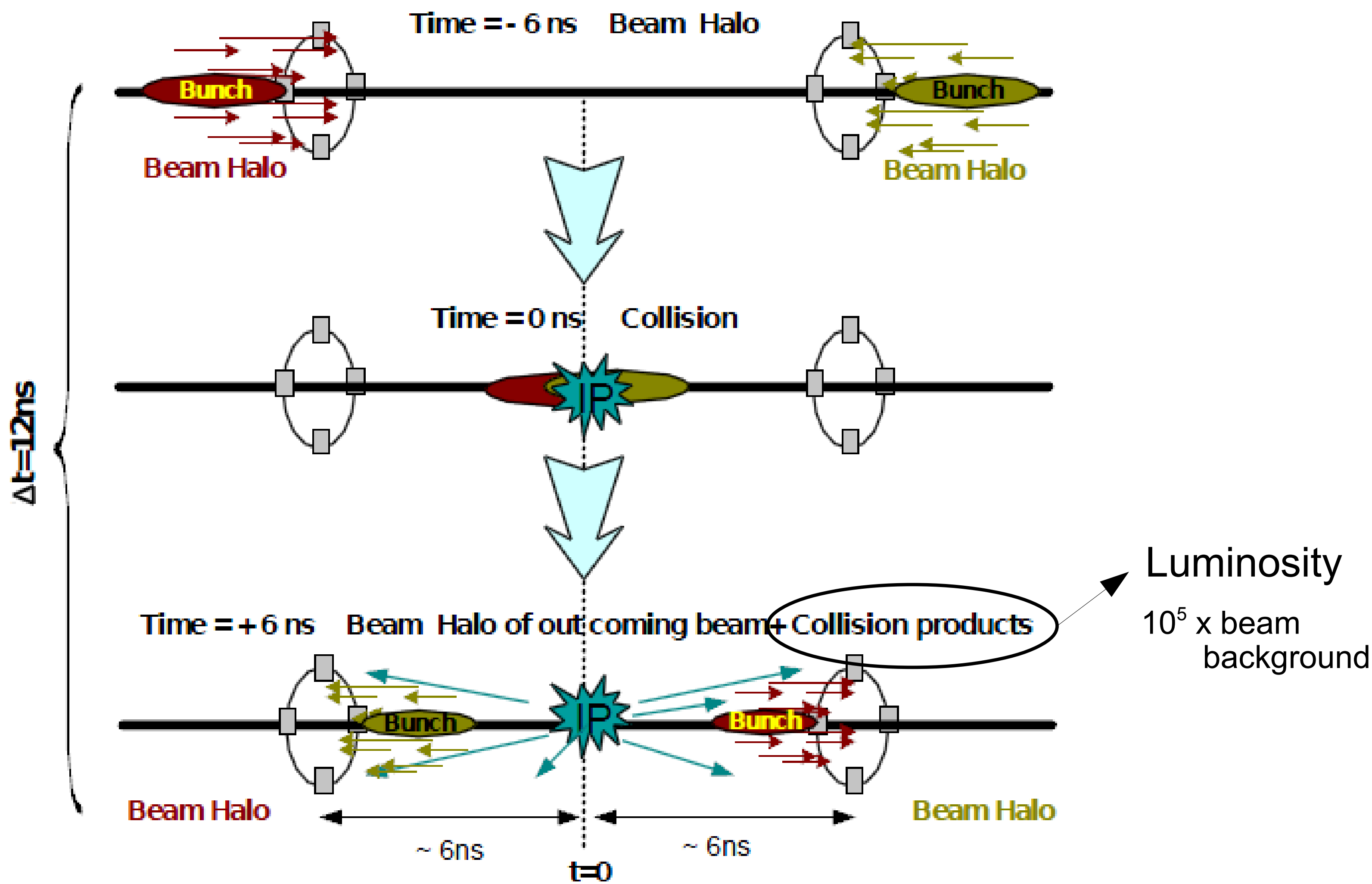






Output: hit rates

Beam Arrival Times



Small geometric acceptance: only “see” small fraction of bunches

Luminosity Measurement

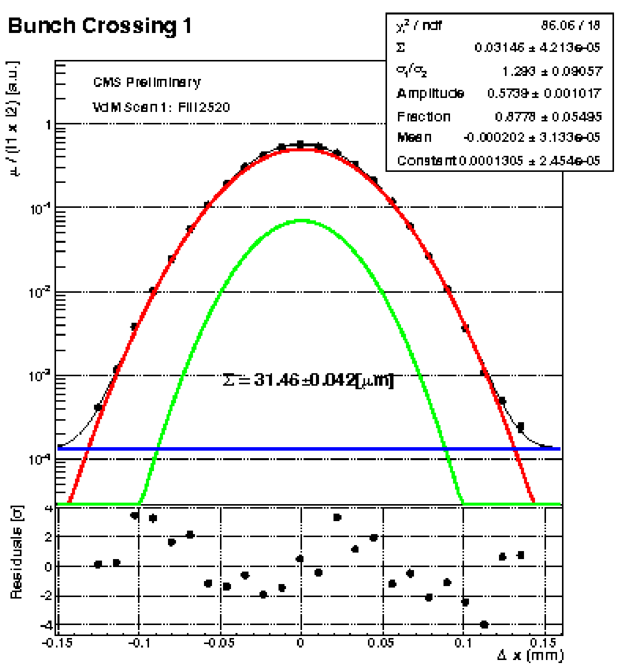
Luminosity scales linearly with hit rate

Non-trivial part: calibration

Van der Meer scan

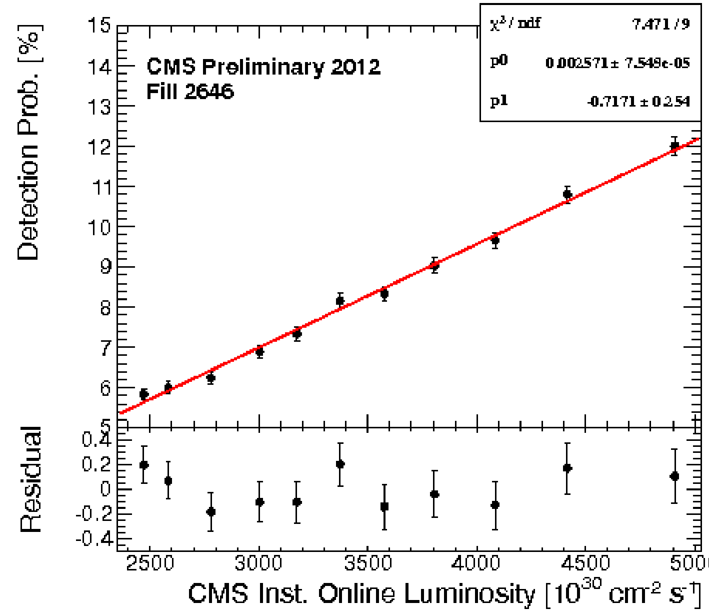
- Scan beams across each other in x,y
- Measure rate at each separation point

Width gives calibration constant



$$L = \frac{\mu_{vis} \cdot n_b \cdot f_{orbit}}{\sigma_{vis}}$$

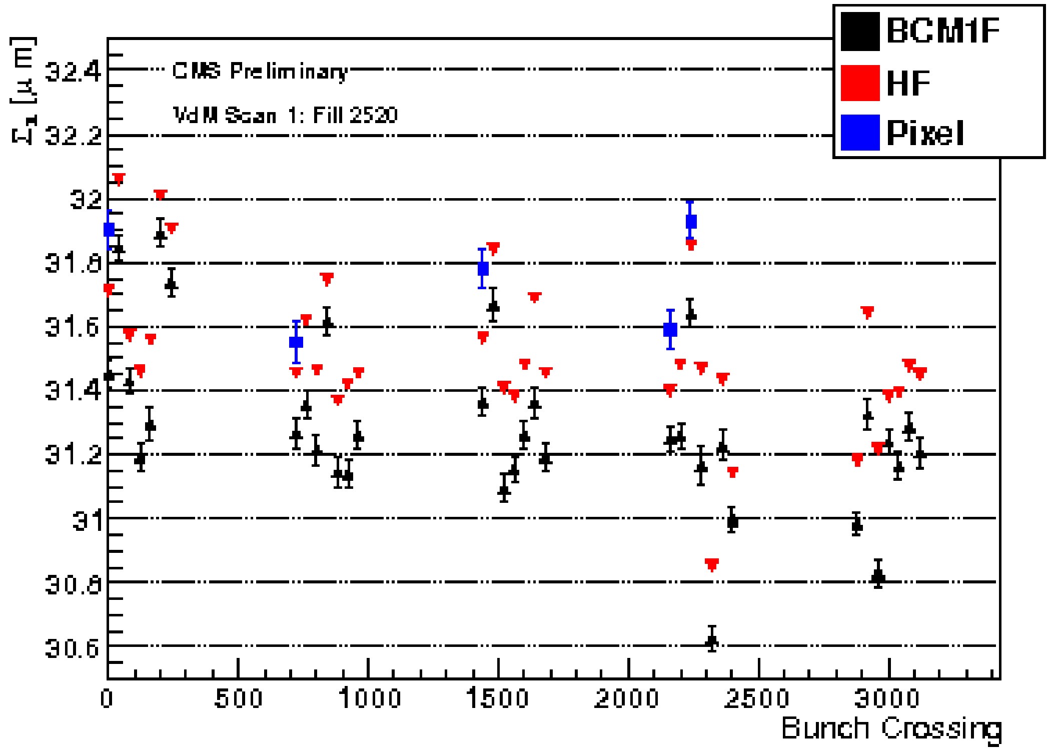
$$L = \frac{f_{rev} N_1 N_2}{2\pi \Sigma_x \Sigma_y}$$



Hit probability: linear extrapolation to higher (upgrade) luminosities reasonable

Comparison to Other Subdetectors

- Compare bunch-by-bunch measured beam width to that measured by other luminosity subdetectors
- Agreement within 1% on average



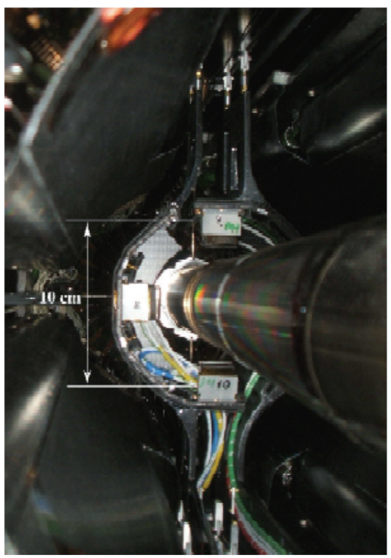
BCM1F Upgrade Concept

Implications of LHC upgrade for BCM1F

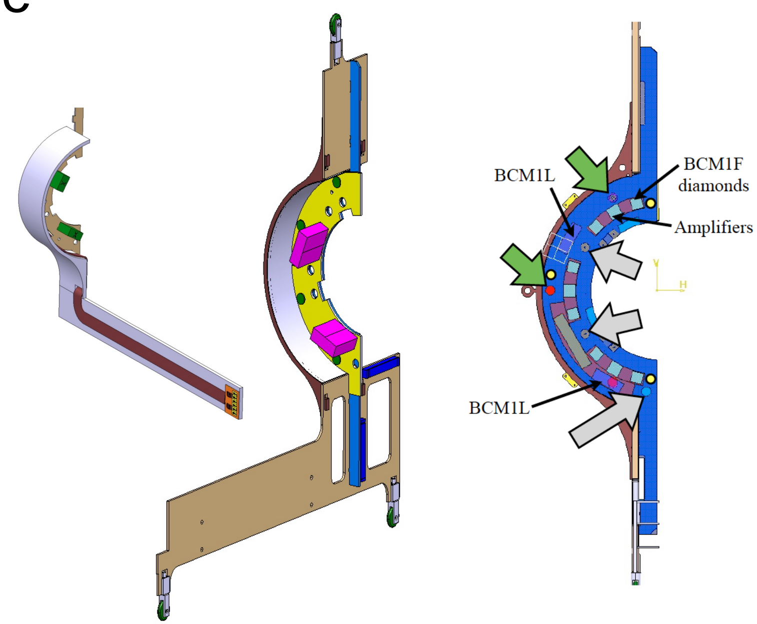
- Radiation: Luminosity 10^{34} $cm^{-2}s^{-1}$ → BCM1F charged particle flux ~$3x10^{7}$ $cm^{-2}s^{-1}$
- 25 ns bunch spacing – current electronics not fast enough
- High rate: more channels = better precision

24 diamonds x 2 metallization pads per diamond = 48 channels

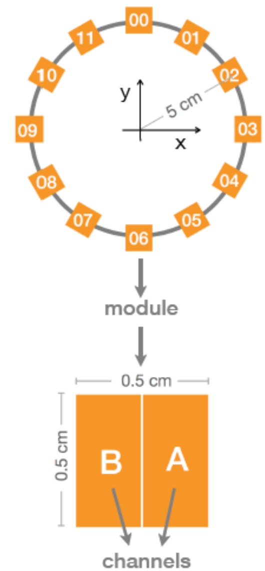
Carbon fiber carriage



Old carriage



Carriage for upgrade



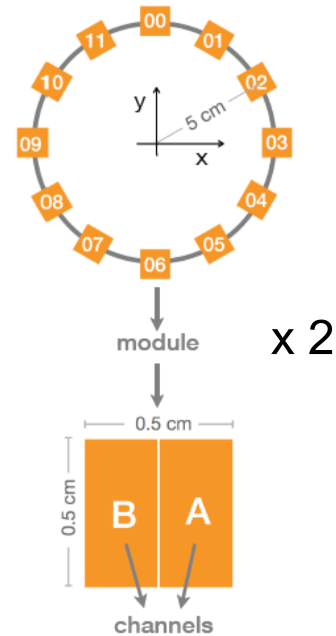
x 2

Upgrade sensor layout

BCM1F Diamonds for Upgrade

Significant issue in Run I: radiation damage

- Effect: diamond polarization decreases efficiency



Primary line of defense: higher HV

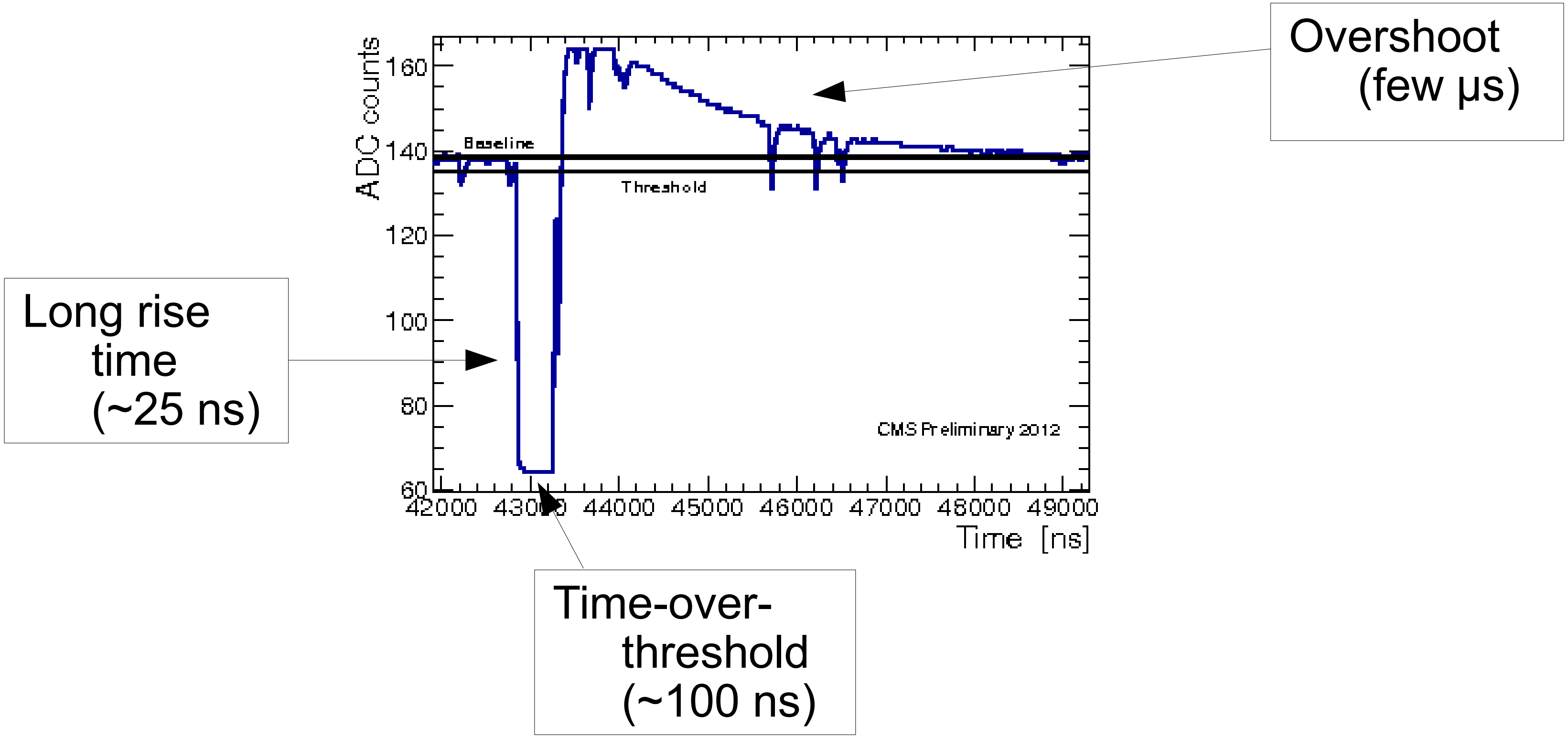
Other possibilities

- Red light illumination
- Alternating voltage polarity

Old and new diamonds currently being characterized with split metallization

Improving Front End Electronics

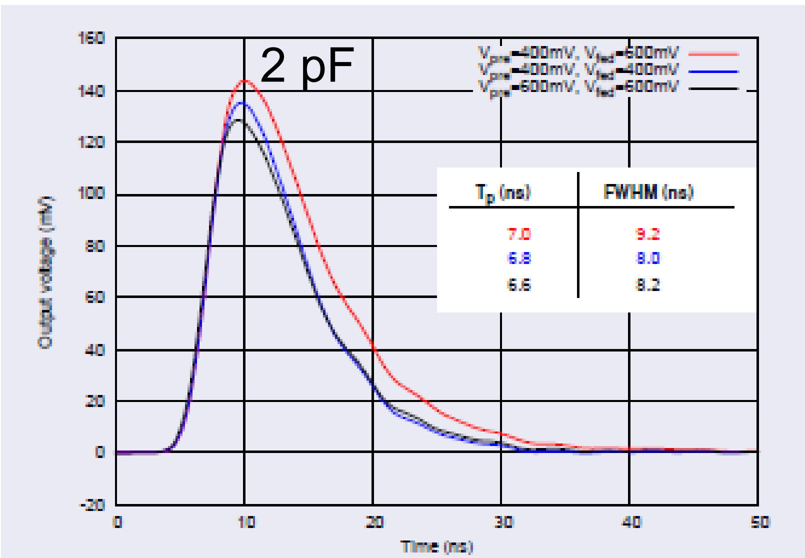
Several sources of inefficiency in front-end electronics, especially for high-amplitude signals

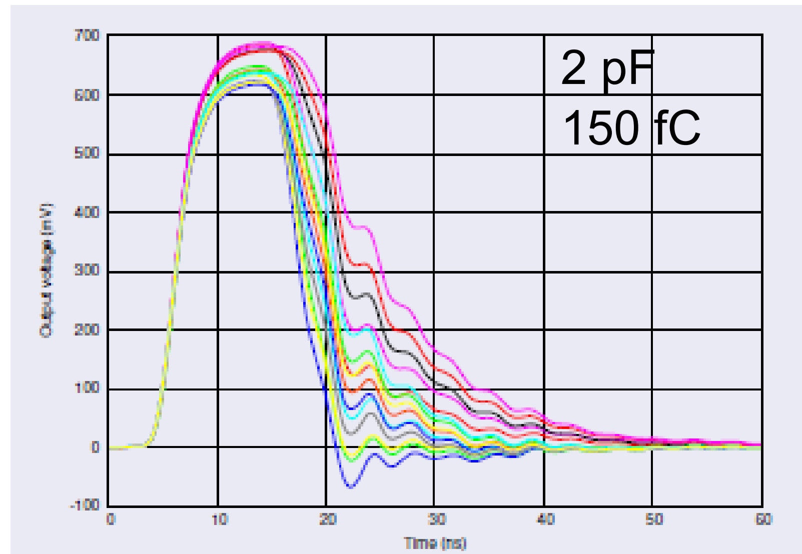


New Fast Front End ASIC

Developed by AGH - Krakow

IBM CMOS8RF 130nm technology





Rise time ~ 7 ns

Time-over-threshold < ~30 ns

Overshoot time very small

Large improvement in behavior: addresses previous problems

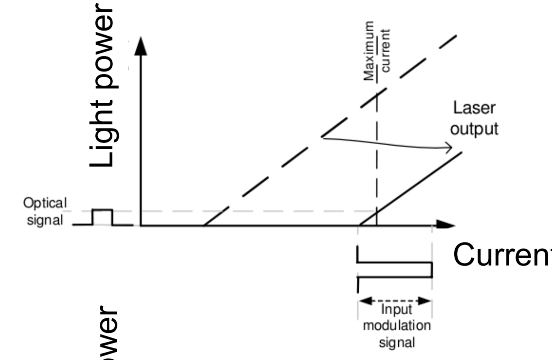
Improving Optical Chain

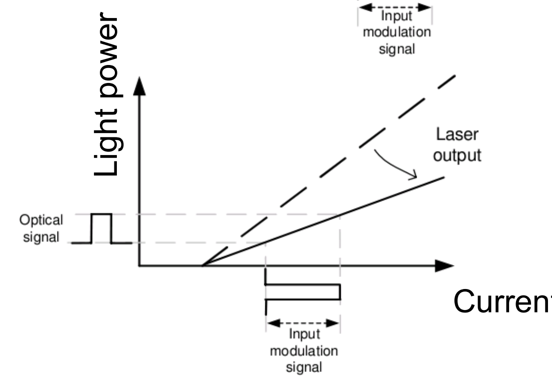
Radiation damage of laser driver visible in decreasing signal amplitude

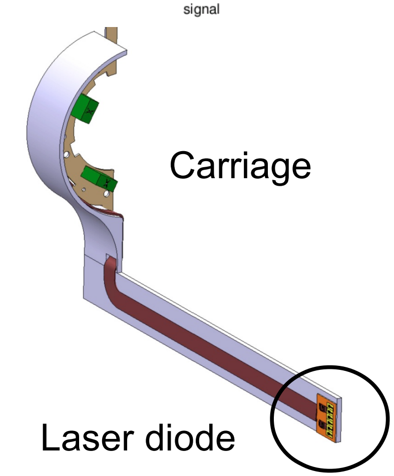
- 25% gain lost in BCM1F optical transmission after 30 fb^{-1}, fluence 8.78×10^{13} cm^{-2} (24 GeV protons)

Improvements

- Multi-amplitude test pulse to monitor linearity of response
- Laser diodes on carriage arm (lower radiation)
- Temperature sensor to account for optical response to temperature
  - Bragg grating: wavelength of transmitted light sensitive to temperature changes
- Temperature stabilization (other subsystems)





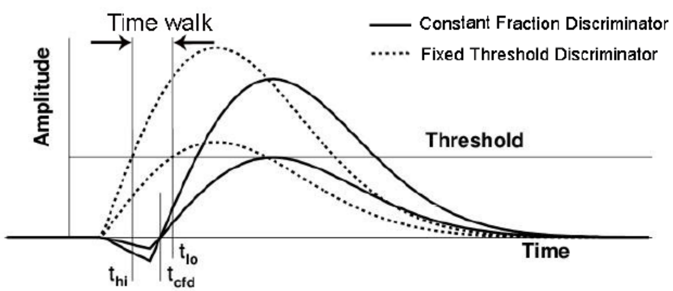


Upgrading Back End Electronics

Two parallel tracks:

Discriminator path

Fixed-threshold vs. constant-fraction

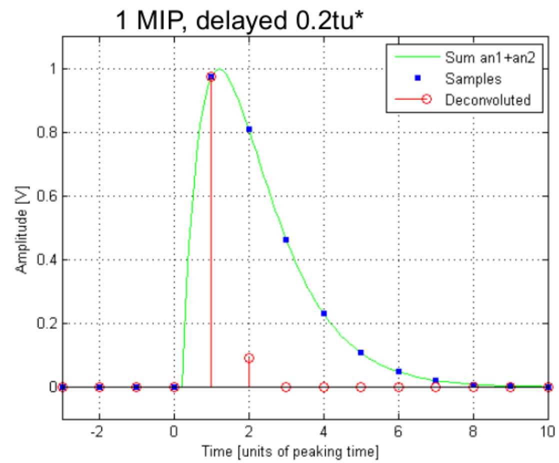


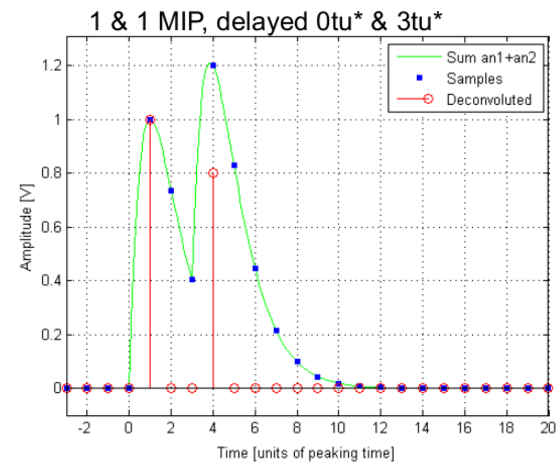
Constant-fraction: better time resolution

Fixed-threshold: lower deadtime

Preliminary conclusion: deadtime outweighs resolution -> use FTD for primary path but install CFD to run in parallel

Digitizer with fast peak-finding algorithms





*tu – time units

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

Many algorithms have been looked at, investigation ongoing

Hardware options for digitizer being explored

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

Upgrading Data Acquisition: RHU

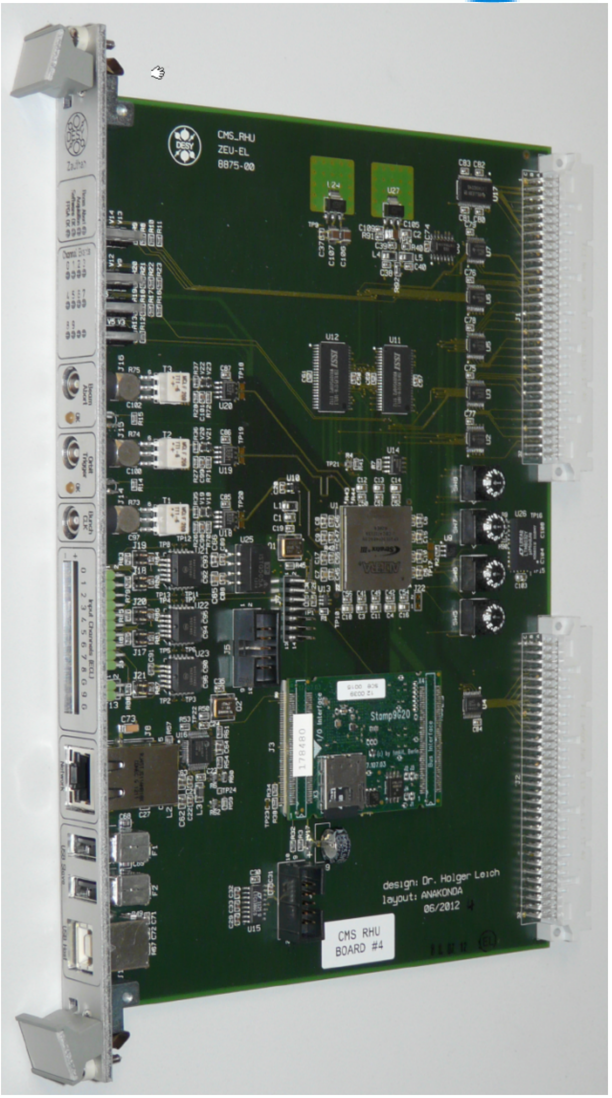
Recording Histogram Unit (RHU): Readout of full-orbit histograms

- No deadtime
- 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

Next revision: Optical fiber input (timing signal), ECL input mezzanine connection



Upgrading Data Acquisition: LumiDAQ

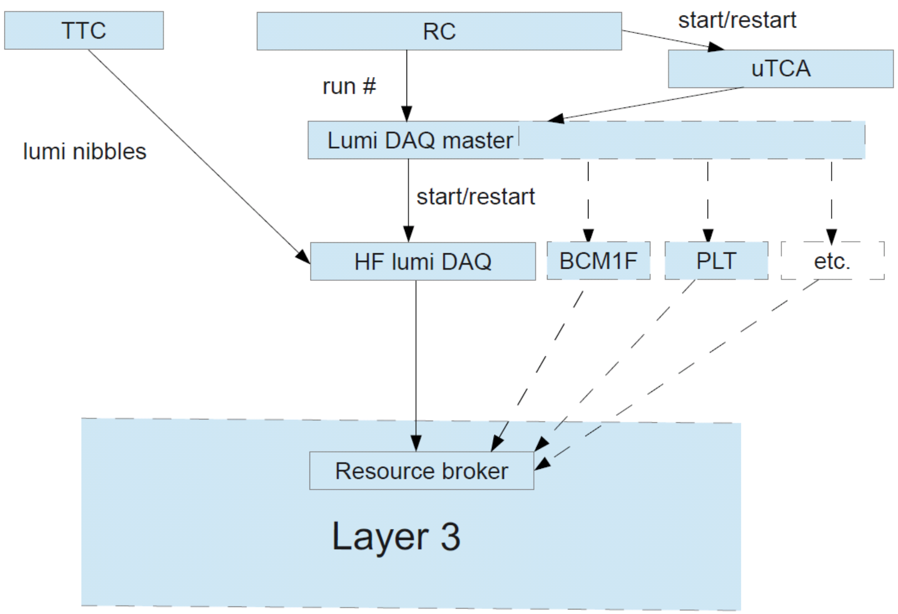
BCM1F output hit rates acquired via LumiDAQ system

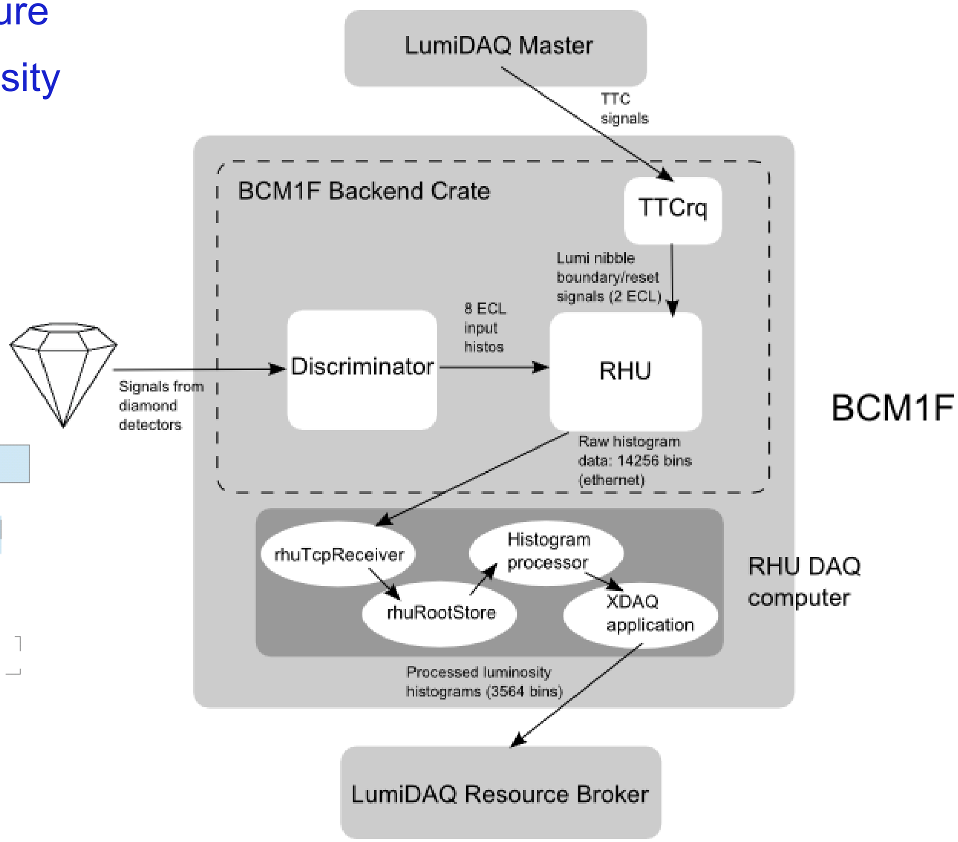
- Expansion of already-existing structure
- Combines data from all CMS luminosity detectors

Common timing signal distributed via optical fiber

- Hit count integration interval

Common data format: 3564 bins

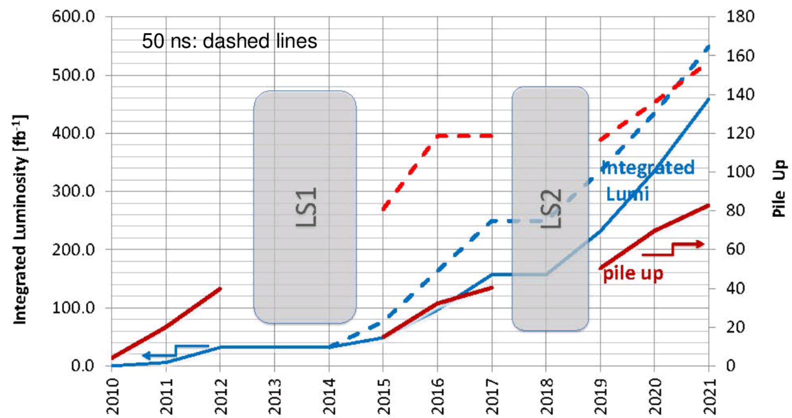




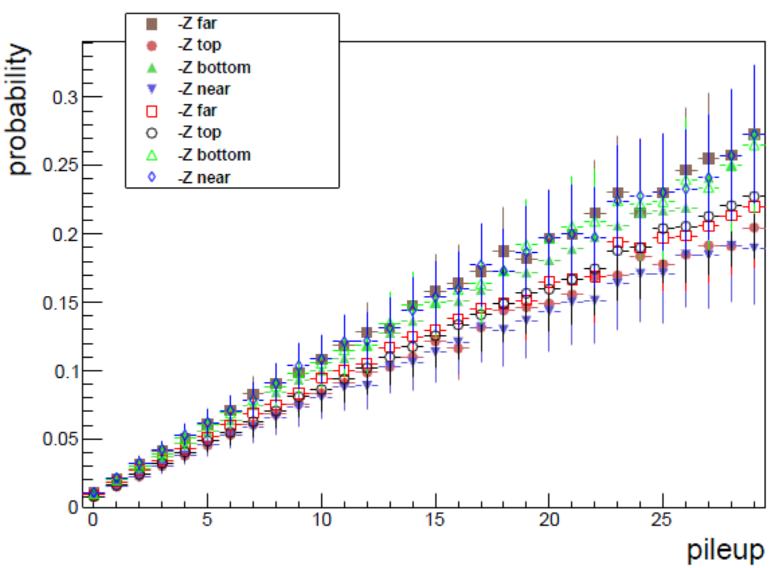
Luminosity Algorithms for Upgrade

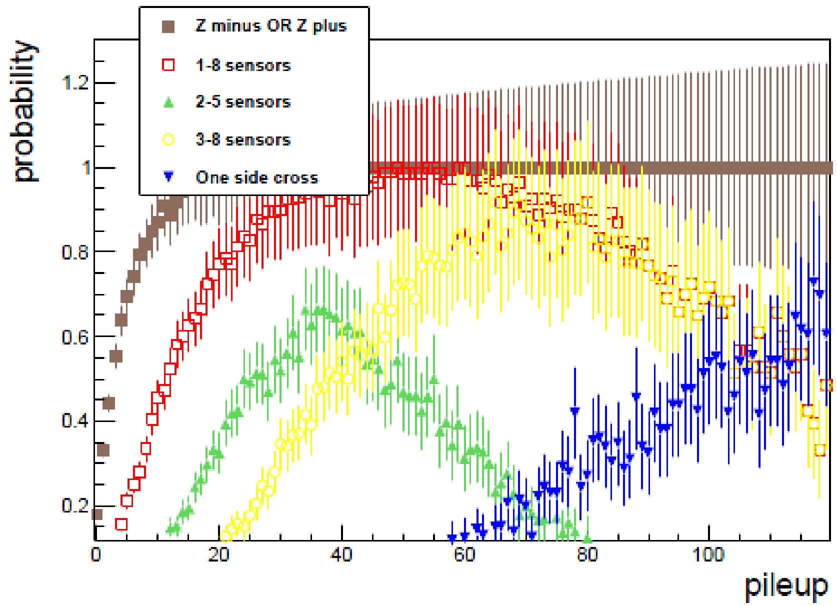
Simple combinations of sensors used to measure luminosity in Run I

– Saturation at high pileup levels foreseen post-upgrade



Development of new algorithms in progress using simulated events





Conclusions

BCM1F showed potential as online luminometer in 2012

- Luminosity calibration agreed with other systems' to within 1%
- Hit rate linear over range of luminosities, extrapolation to post-upgrade period reasonable

Improvements in the works to increase effectiveness

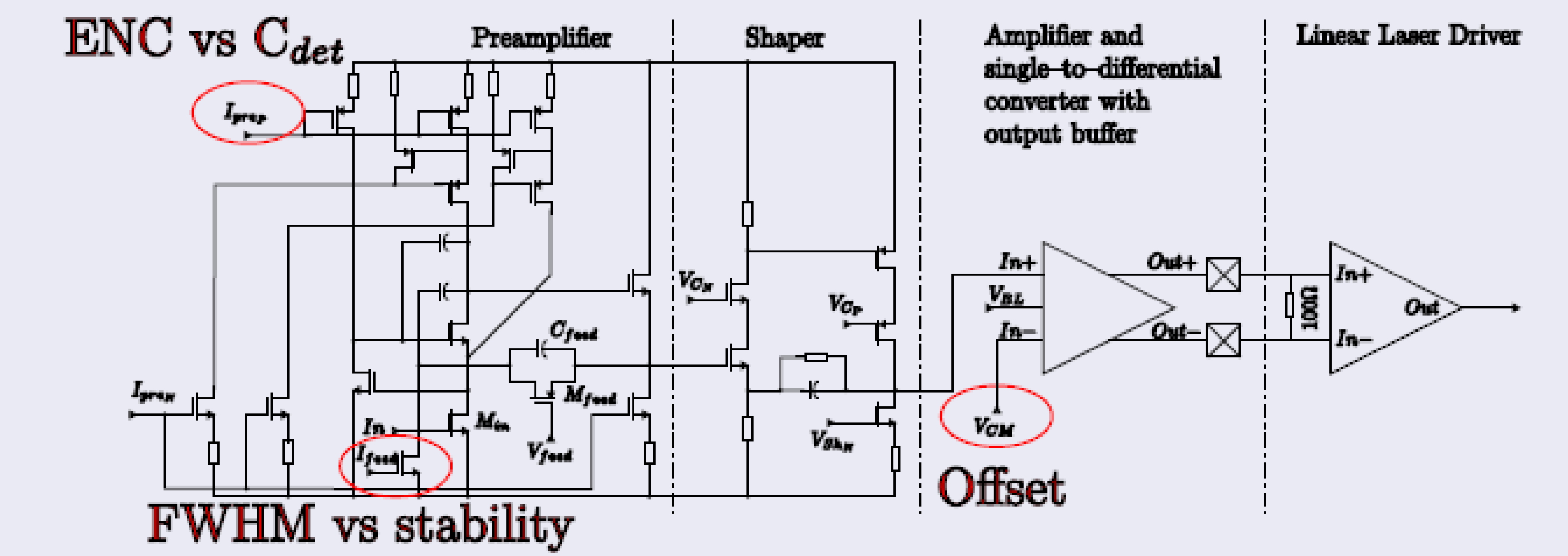
- Sensors: minimize effects of radiation damage using higher voltage
- New fast front end ASIC to reduce inefficiencies
- Optical chain: lower radiation for laser driver, multi-amplitude test pulses
- Back end: Discriminator in parallel with digitizer peak-finding
- RHU, LumiDAQ for collection of hit rates
- Algorithms for luminosity measurement in post-upgrade conditions under development

Future plans

- Full sensor chain to be re-tested after irradiation
- Synchronization of readout electronics within timing/LumiDAQ framework

FE ASIC specs

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)

Luminosity Basics

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

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

- $\mu \equiv$ 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,

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