Current Status of the Fast Beam Condition Monitor Upgrade at CMS

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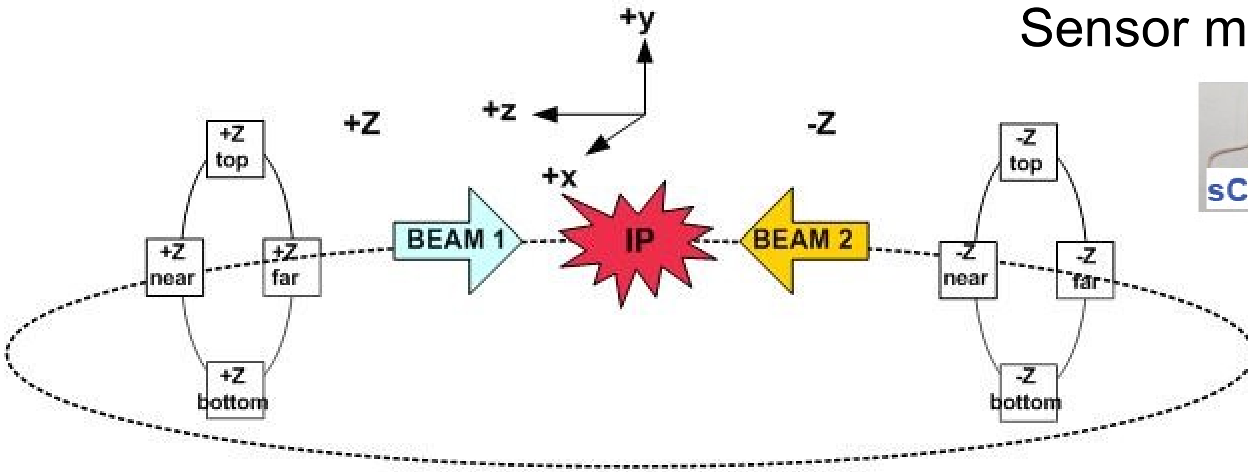
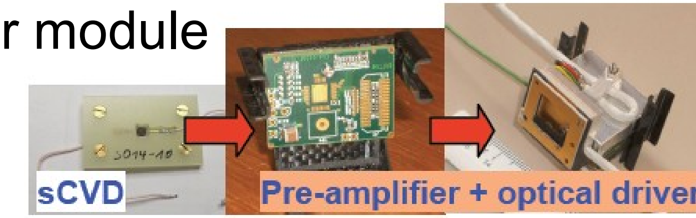
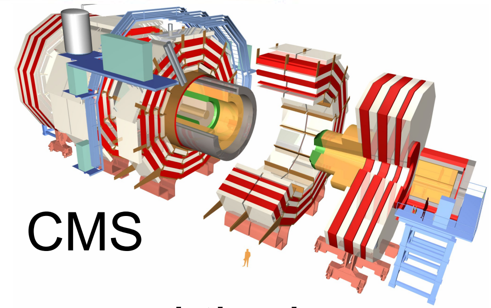
DPG Frühjahrstagung

Fast Beam Condition Monitor BCM1F (up to 2012)



Sensor module

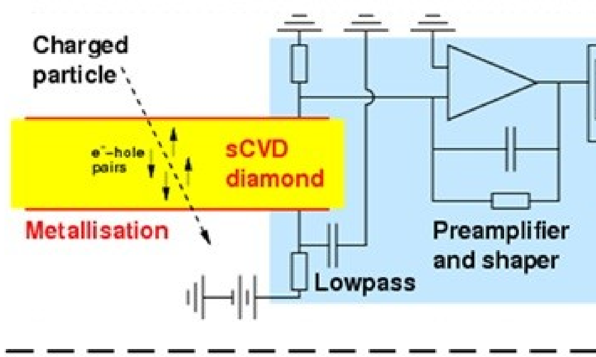


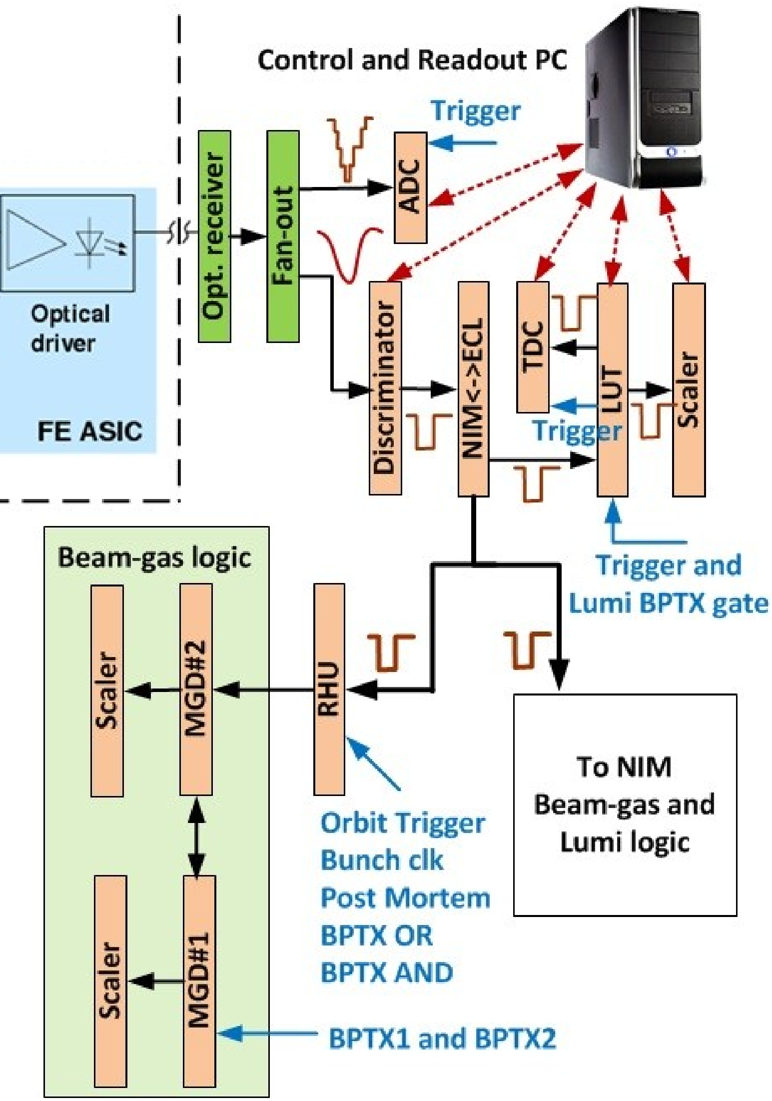


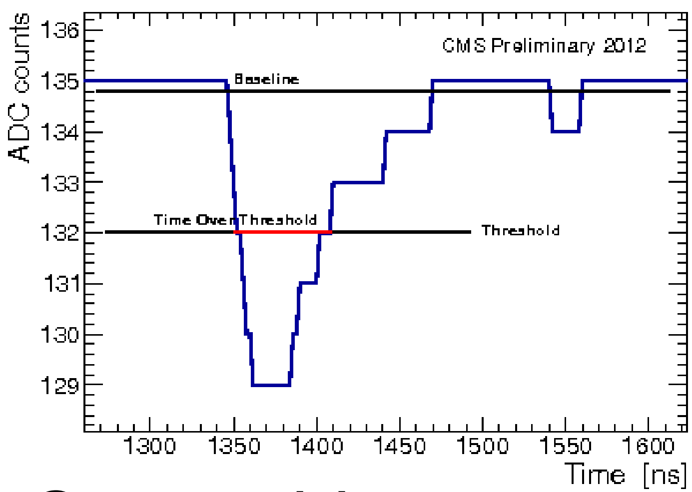
CMS

- 8 5mm x 5mm single-crystal CVD diamonds positioned around the beam-pipe, radial distance 4.5 cm, 1.8 m from interaction point
  - Diamond → no cooling, good signal-to-noise ratio, 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, power independent of CMS

BCM1F Electronics

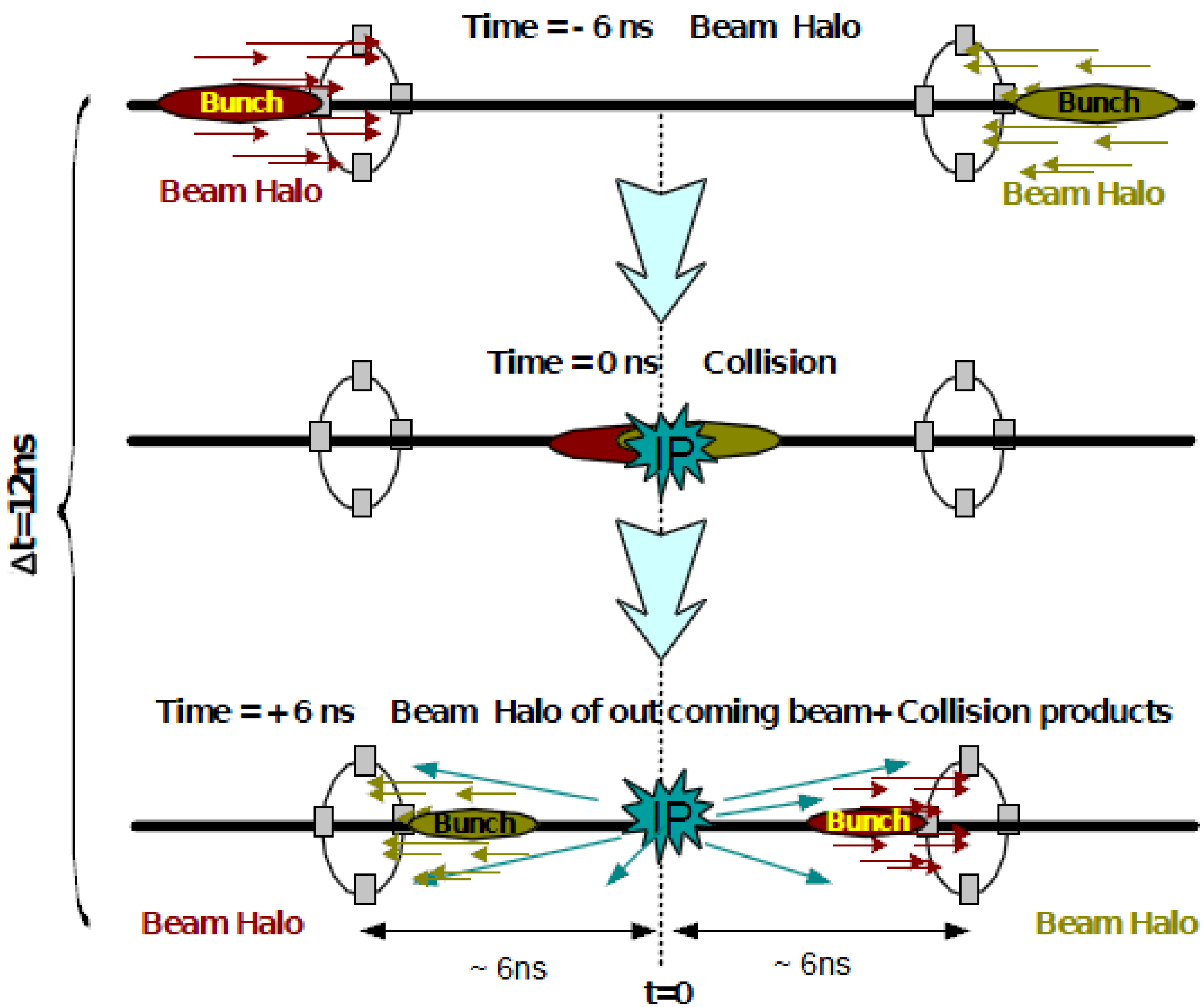






Output: hit rates

Beam Arrival Times



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

Luminosity Measurement

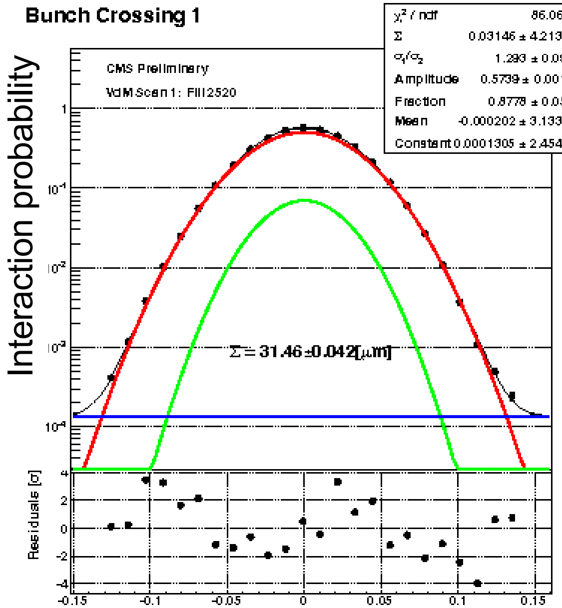
Luminosity scales linearly with hit rate

Non-trivial part: calibration

Van der Meer scan

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

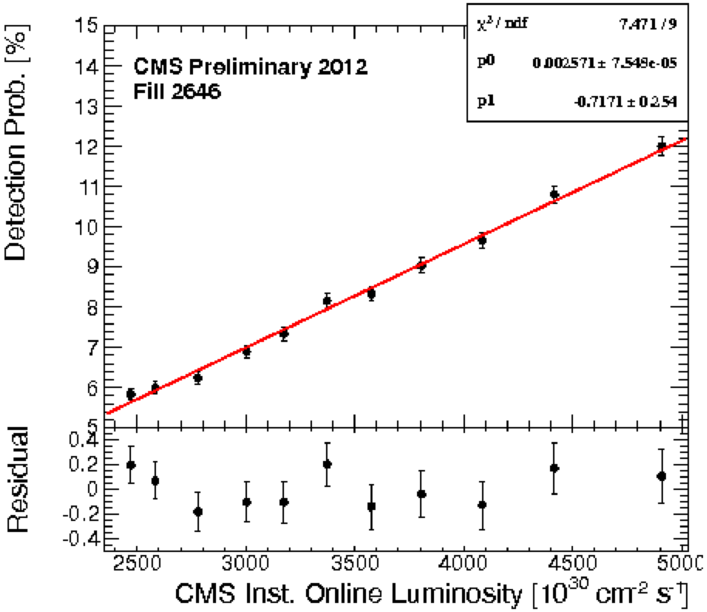
Calibration constant extracted from fit (width)



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

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

$$\mu = -\ln[p(0)]$$



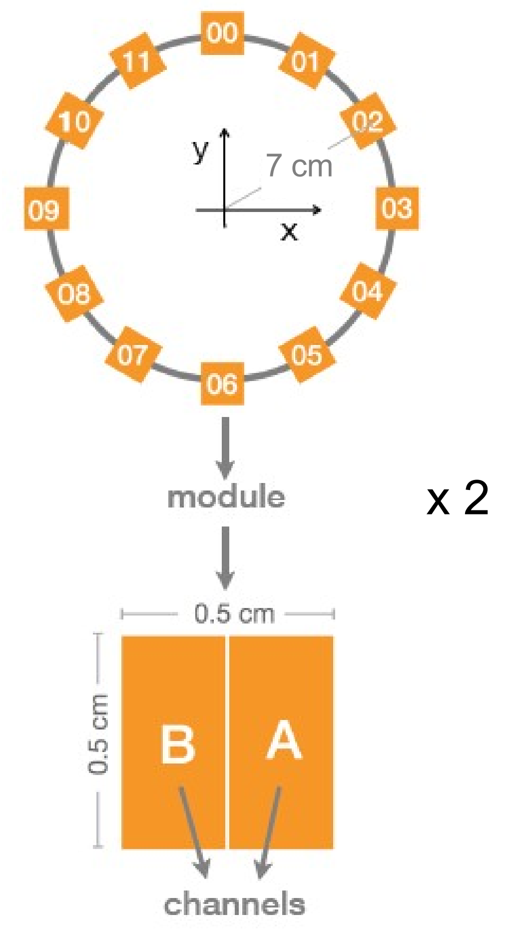
BCM1F Upgrade

Implications of LHC upgrade for BCM1F

- High hit rate: Luminosity 10^{34} cm^{-2}s^{-1} → BCM1F charged particle flux ~3×10^{7} cm^{-2}s^{-1}
- 25 ns bunch spacing

Strategy

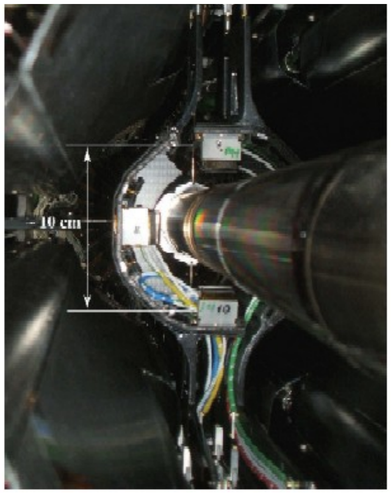
- Higher dynamic range: 24 diamonds x 2 metallization pads per diamond = 48 channels
  - See talk from M. Hempel for diamond specifics
- Scale up full system: 8 → 48 channels
- Faster electronics
- Integrate readout with other luminosity subsystems



Sensor layout for upgrade

Upgrade Carriage Design

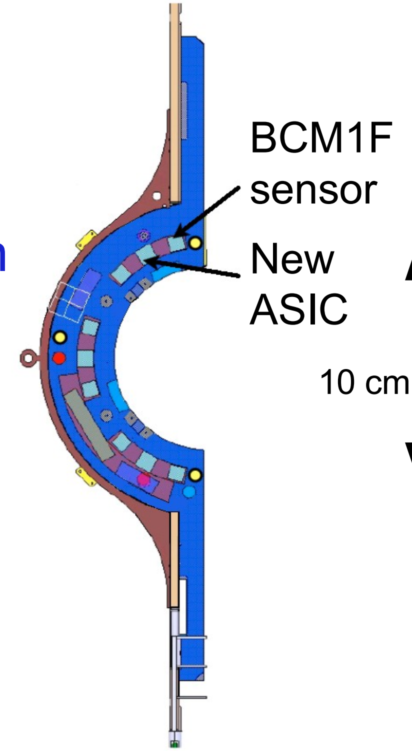
Old carriage

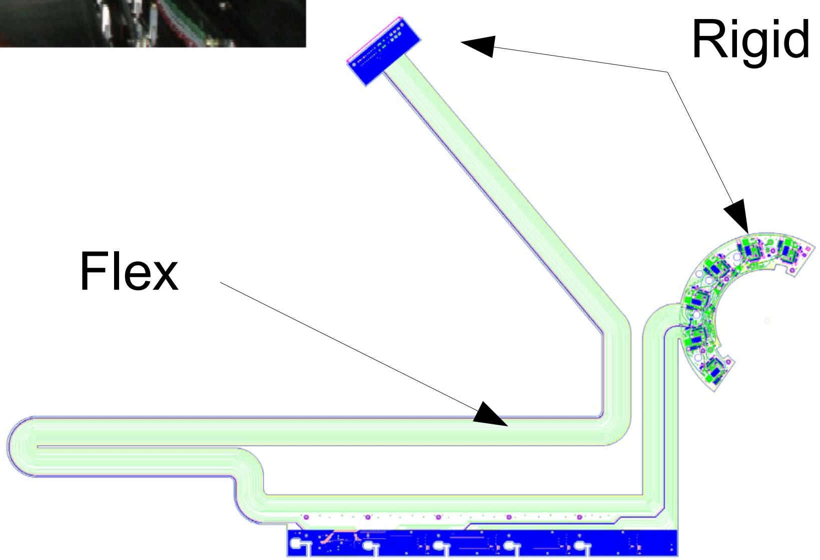


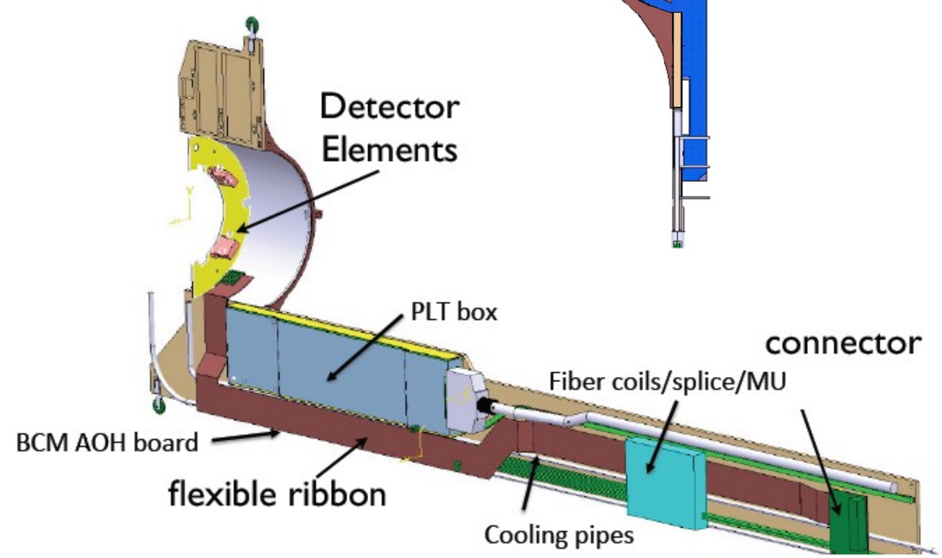
Old: carbon fiber

New: semi-rigid PCB

- Shape allows extended length from single PCB panel
- Currently being produced

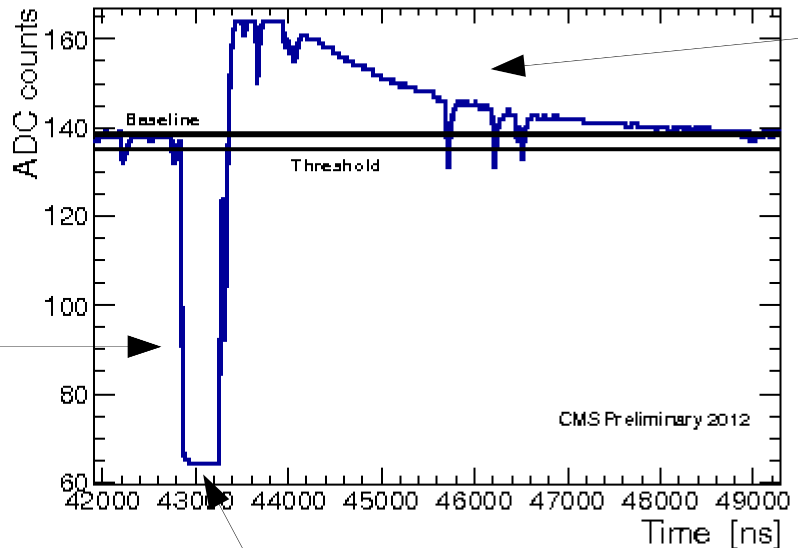






Improving Front End Electronics

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



Overshoot (few μs)

Long rise time (~25 ns)

Time-over-threshold (~100 ns)

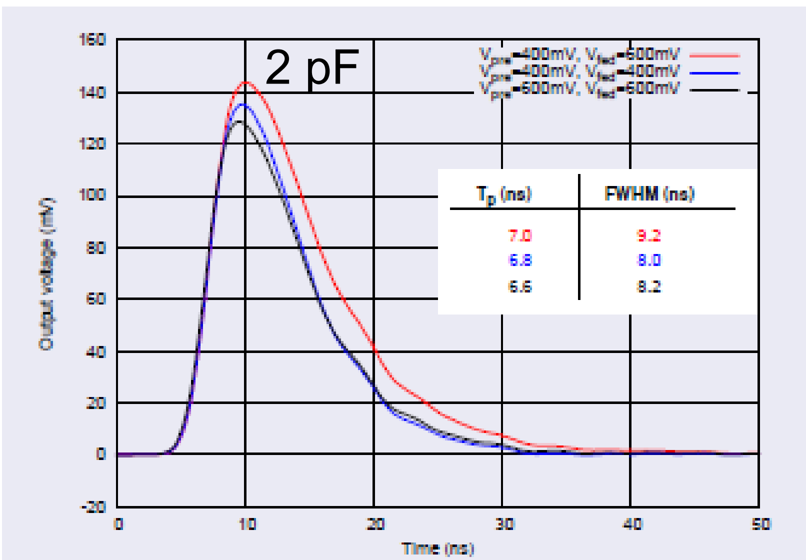
New Fast Front End ASIC

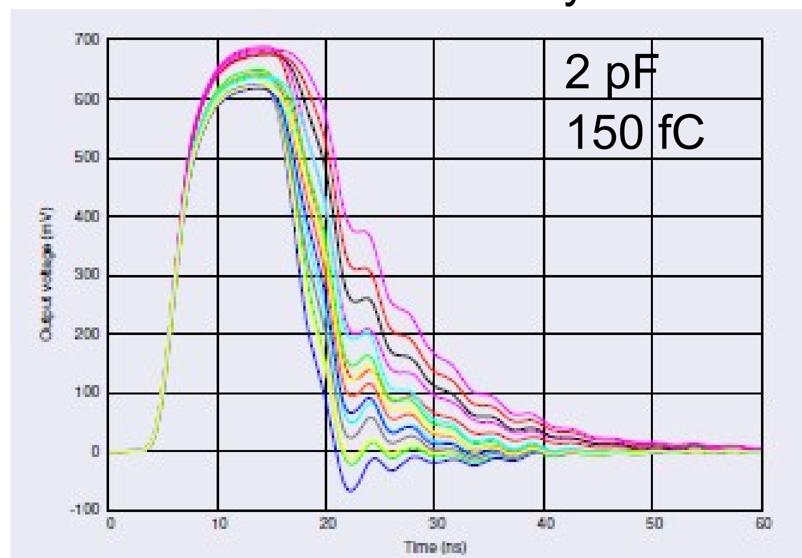
Developed by AGH - Krakow

IBM CMOS8RF 130nm technology

~50 mV/fC charge gain, < 1ke- ENC

D. Przyborowski





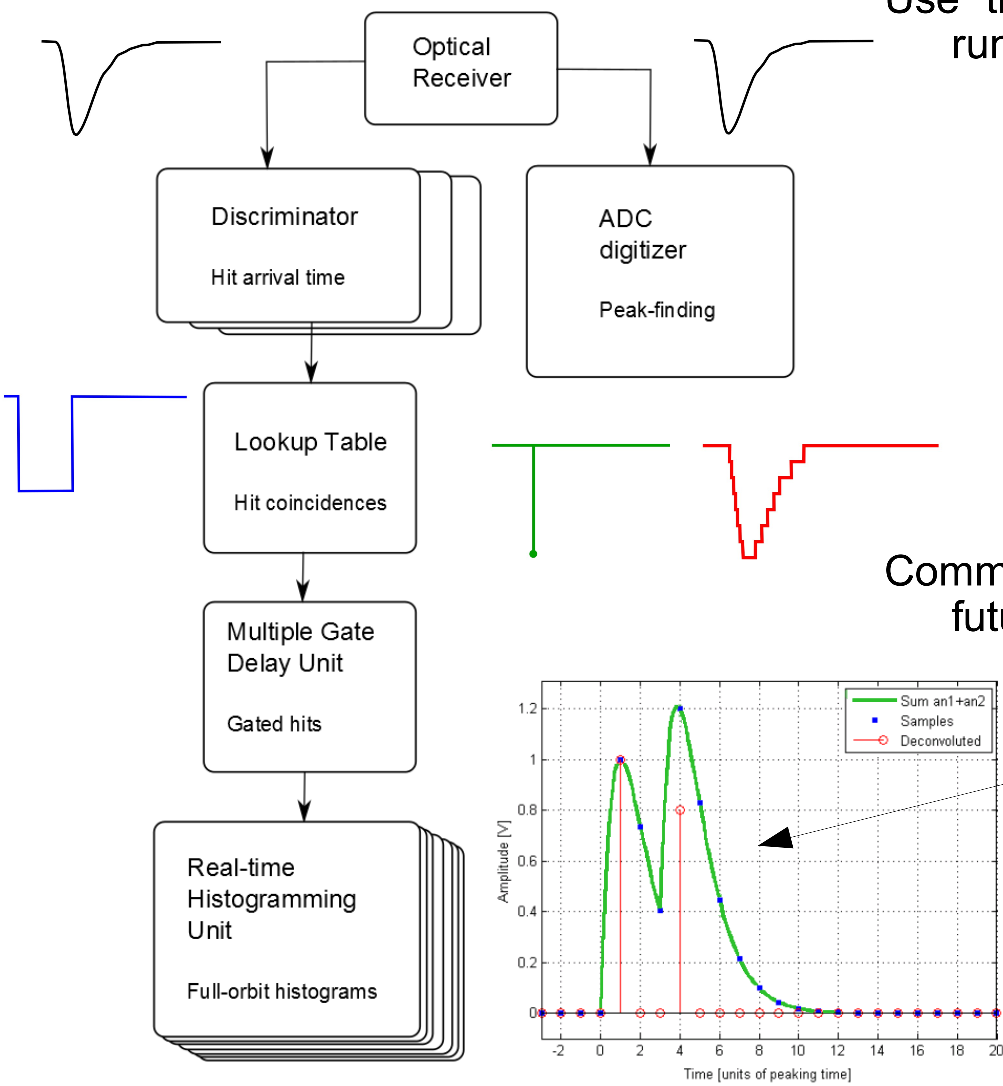
Rise time ~ 7 ns

Time-over-threshold < ~30 ns

Overshoot time very small

Large improvement in behavior: addresses previous problems

Backend Concept for Upgrade: Parallel Paths



Use "tried and true" discriminator path for initial running (VME)

- Fast low-deadtime discriminator to measure hit arrival time
- Lookup Table (LUT): detect coincidences between channels
- Multiple Gate Delay Unit (MGD): Gated signals to pick out background, collisions
- Real-time Histogramming Unit (RHU) for readout (see next slide)

Commission digitizer with fast peak-finding for future use (uTCA)

- Identify pulse arrival time and peak height, distinguish signals close in time (overlapping)
- Hardware being evaluated: FMC mezzanine system. Multiple candidates in testing
- Development of FPGA algorithms in progress
- Also will be used as ADC for efficiency studies

Upgrading Data Acquisition: RHU

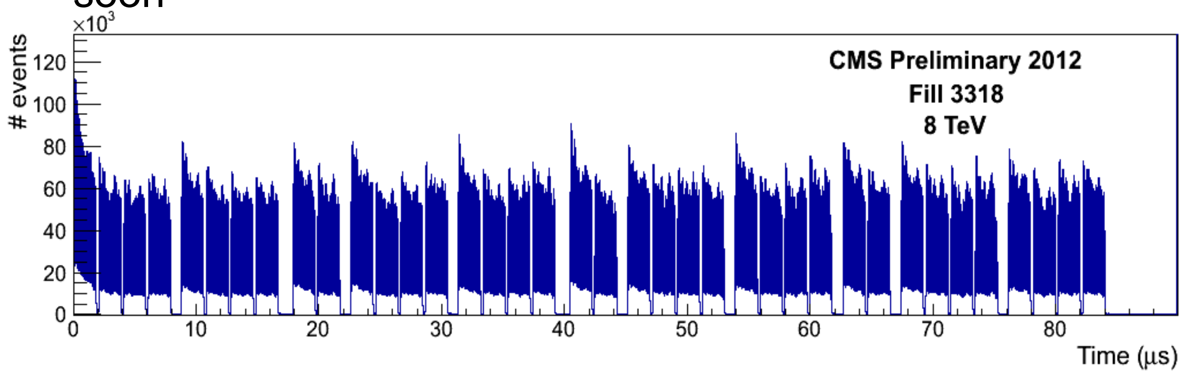
Real-time Histogramming Unit (RHU): Deadtimeless readout of full-orbit histograms

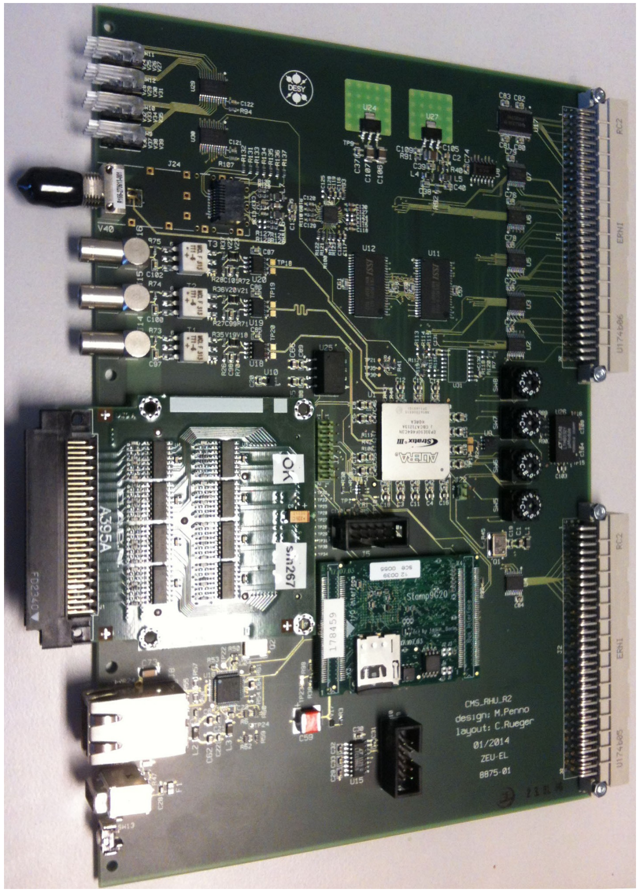
- 8 histogramming input channels: ECL mezzanine
- Bins of 6.25 ns = 4/bunch bucket (14k bins/orbit)
- Bunch clock, orbit clock, beam abort signals (NIM)
- Sampling period from optical timing signal
- 5 Mbit RAM FPGA, on-board embedded Linux system
- Ethernet readout

Developed at DESY-Zeuthen

Rev. 1 prototype installed Sept. 2012, validated during 2012-2013 run

Rev. 2 prototype tested and functional, production to begin soon

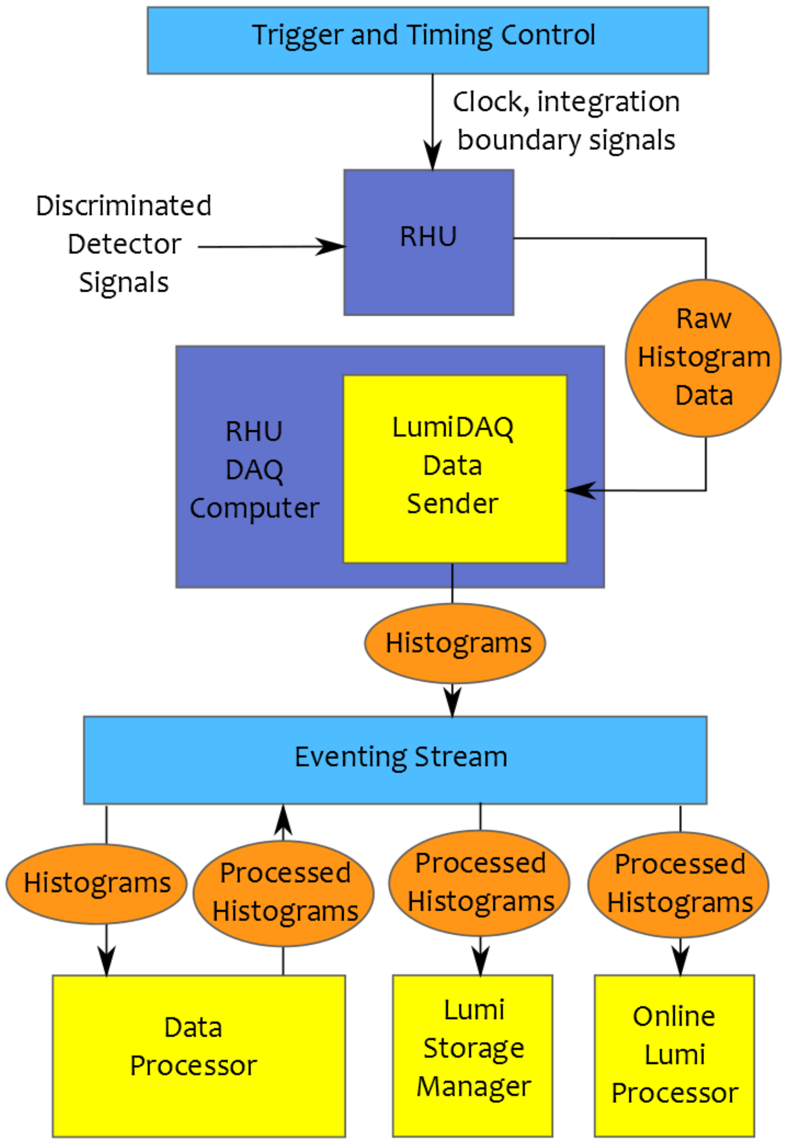




Rev. 2

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
  - Synchronization important
- Eventing stream receives and transmits data to downstream subscribers for processing, storage
- Software framework and components currently being developed



Conclusions

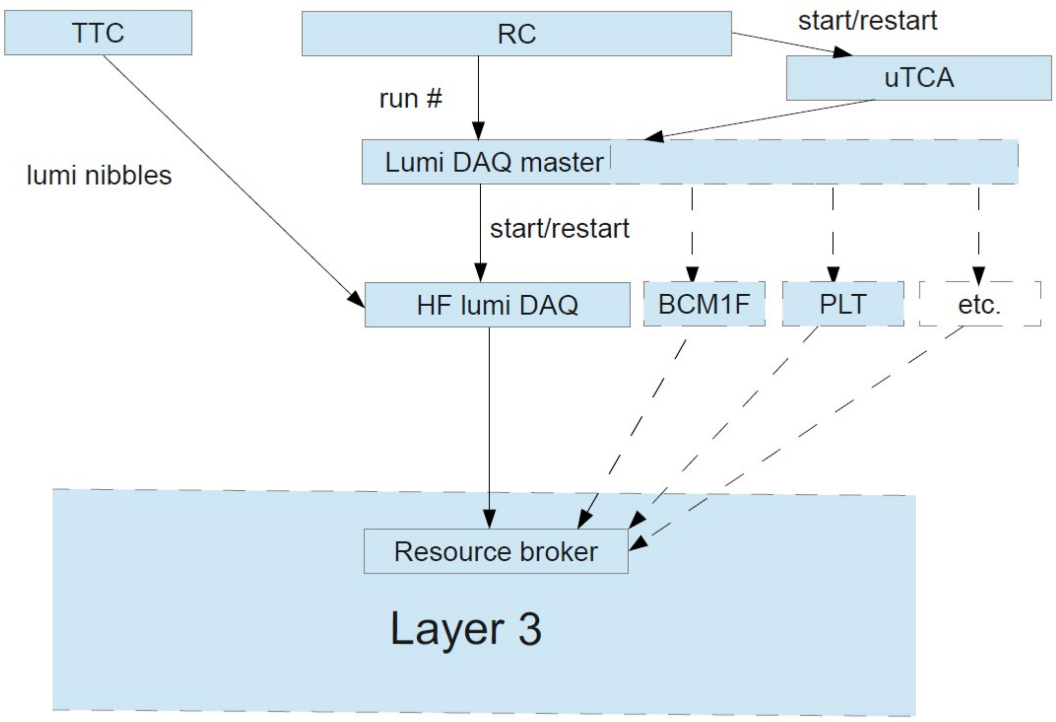
Many improvements in the works to increase BCM1F effectiveness as luminometer

- Carriage: 48 channels, single semi-rigid PCB
- New fast front end ASIC to reduce inefficiencies
- Back end: Discriminator path in parallel with digitizer peak-finding
- Realtime Histogramming Unit for collection of hit rates
- LumiDAQ integration for calculation, publication, and storage of online luminosity values

Future plans

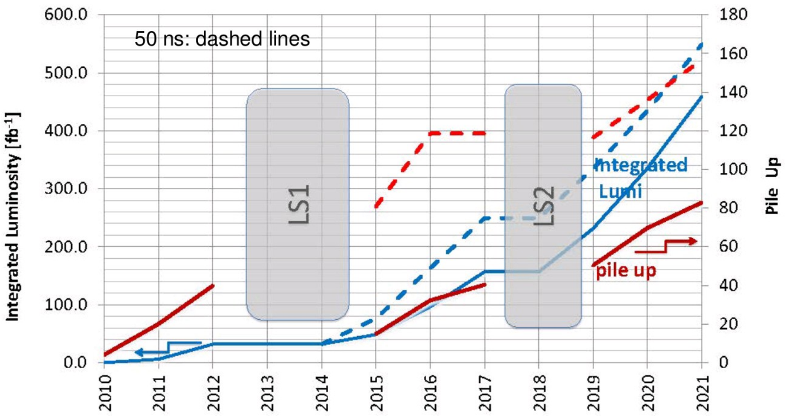
- Produce carriage PCB, RHU boards over next few months
- Synchronize RHU within LumiDAQ framework
- Converge on backend hardware
- Install BCM1F in CMS this fall

LumiDAQ Schematic

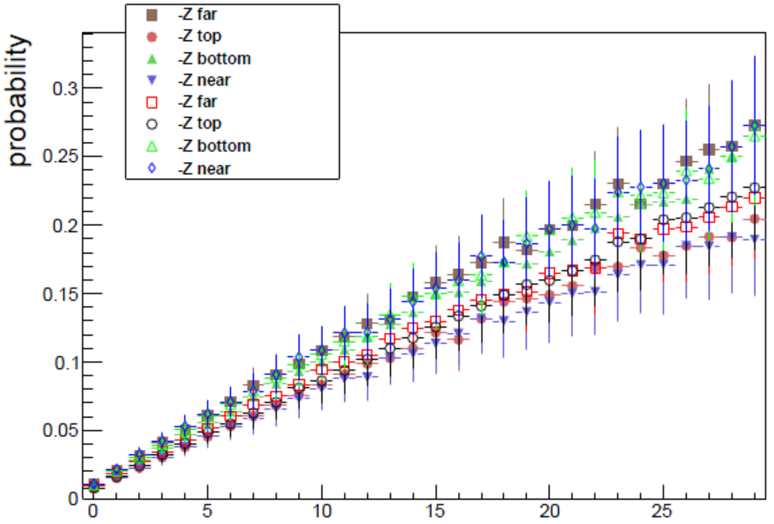


Luminosity Algorithms for Upgrade

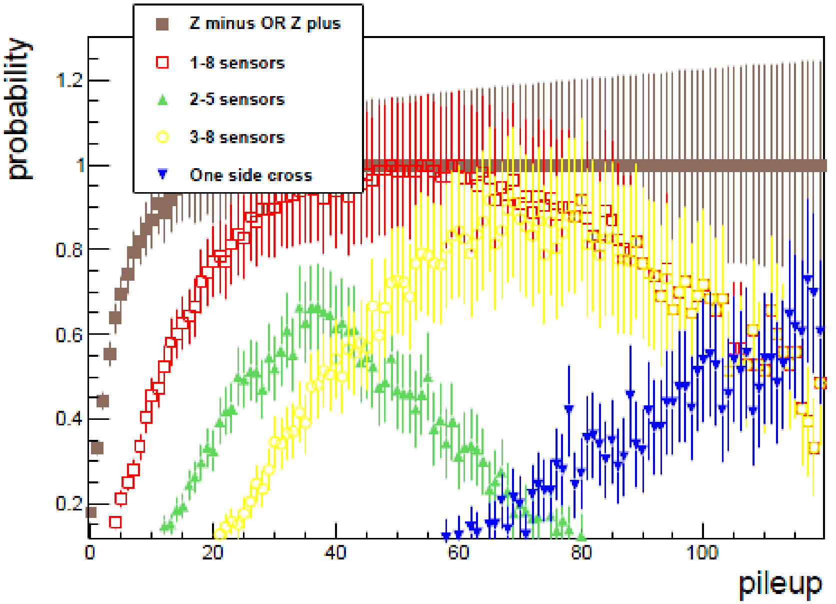
- Simple combinations of sensors used to measure luminosity in Run I
  - Saturation at high pileup levels foreseen post-upgrade



- New algorithms needed, development via simulation



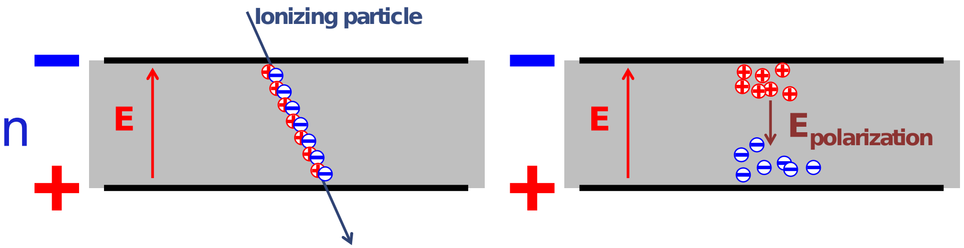
W. Warzycha



BCM1F Diamonds for Upgrade

Significant issue in Run I: radiation damage

- Effect: diamond polarization decreases efficiency

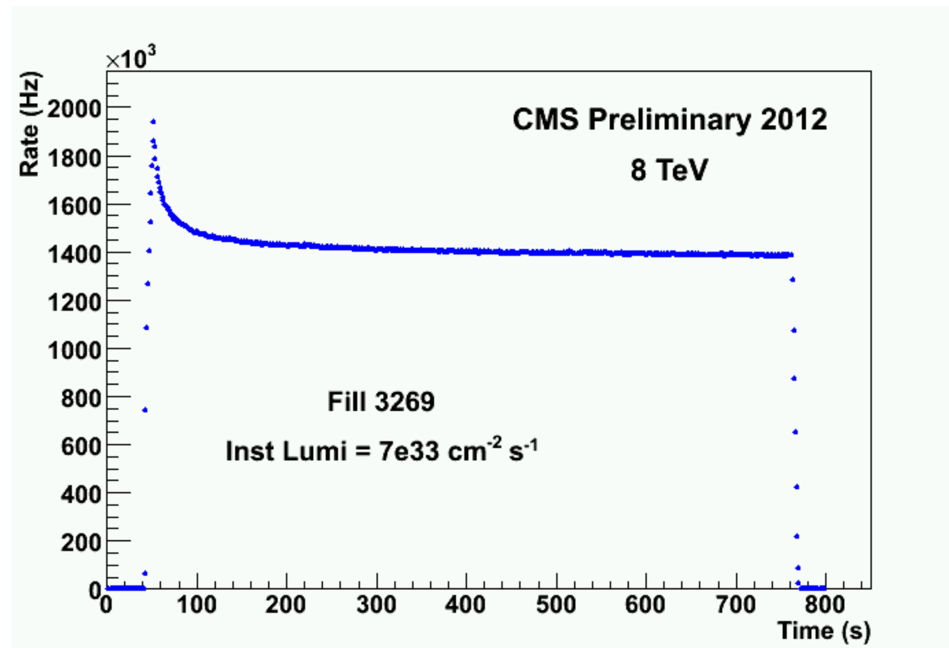


Primary line of defense: higher HV

Other possibilities

- Red light illumination
- Alternating voltage polarity

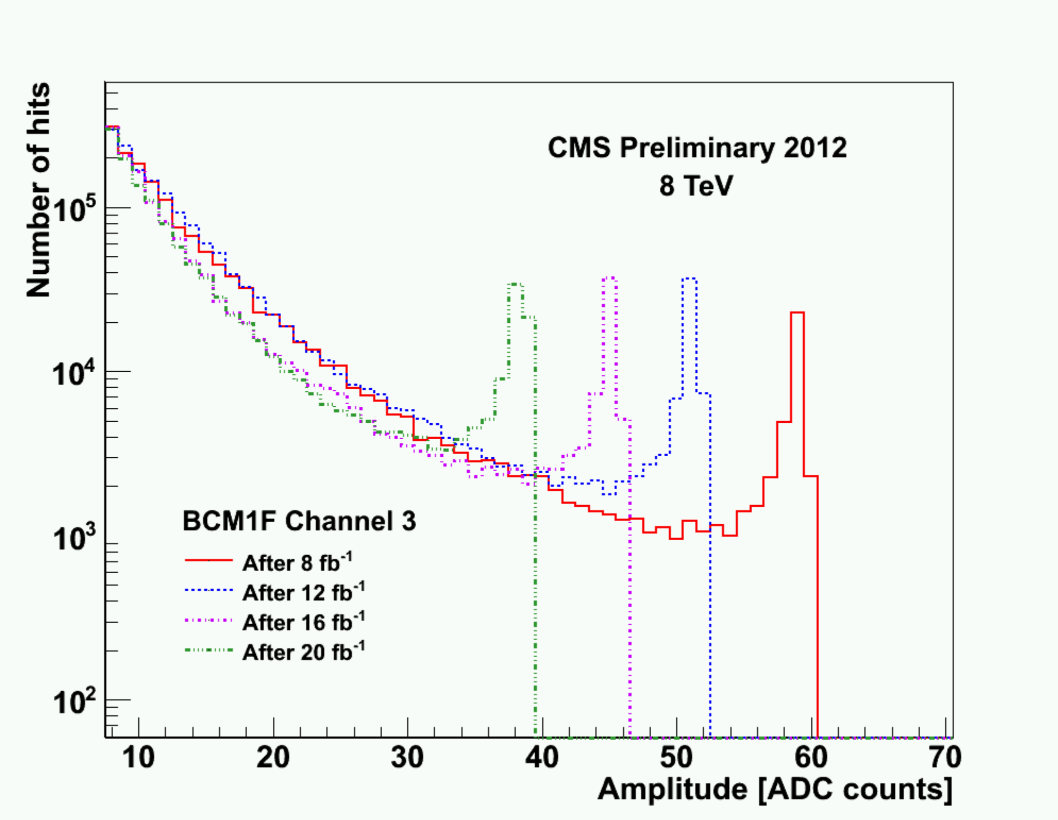
Old and new diamonds recently characterized with split metallization (talk from Maria Hempel)



Improving Optical Chain

Radiation damage of laser driver visible in decreasing signal amplitude

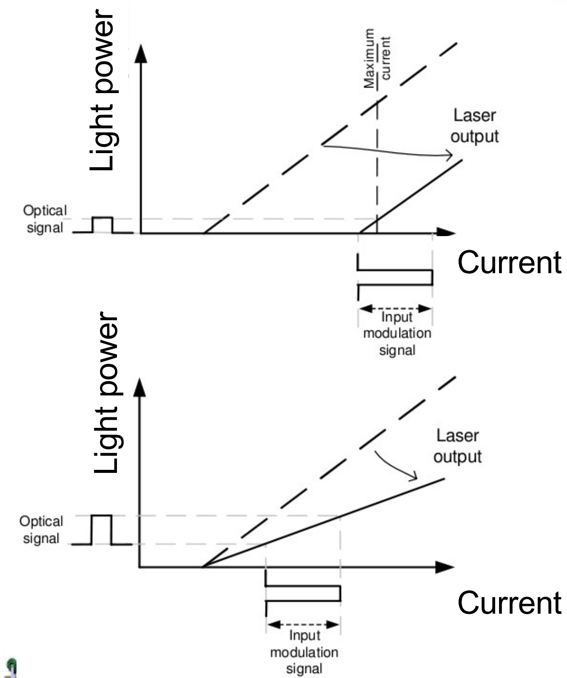
– 25% gain lost in BCM1F optical transmission after 30 fb^{-1}, fluence 8.78×10^{13} cm^{-2} (24 GeV protons)

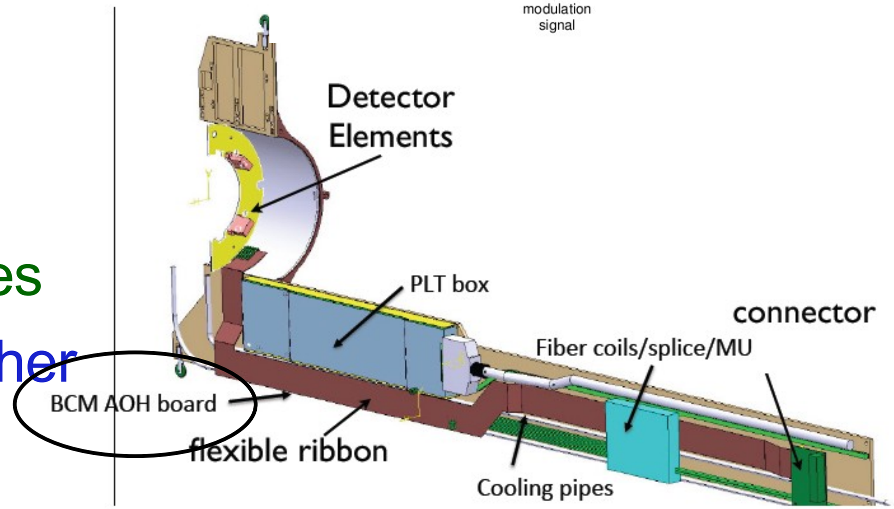


Improving Optical Chain

Improvements

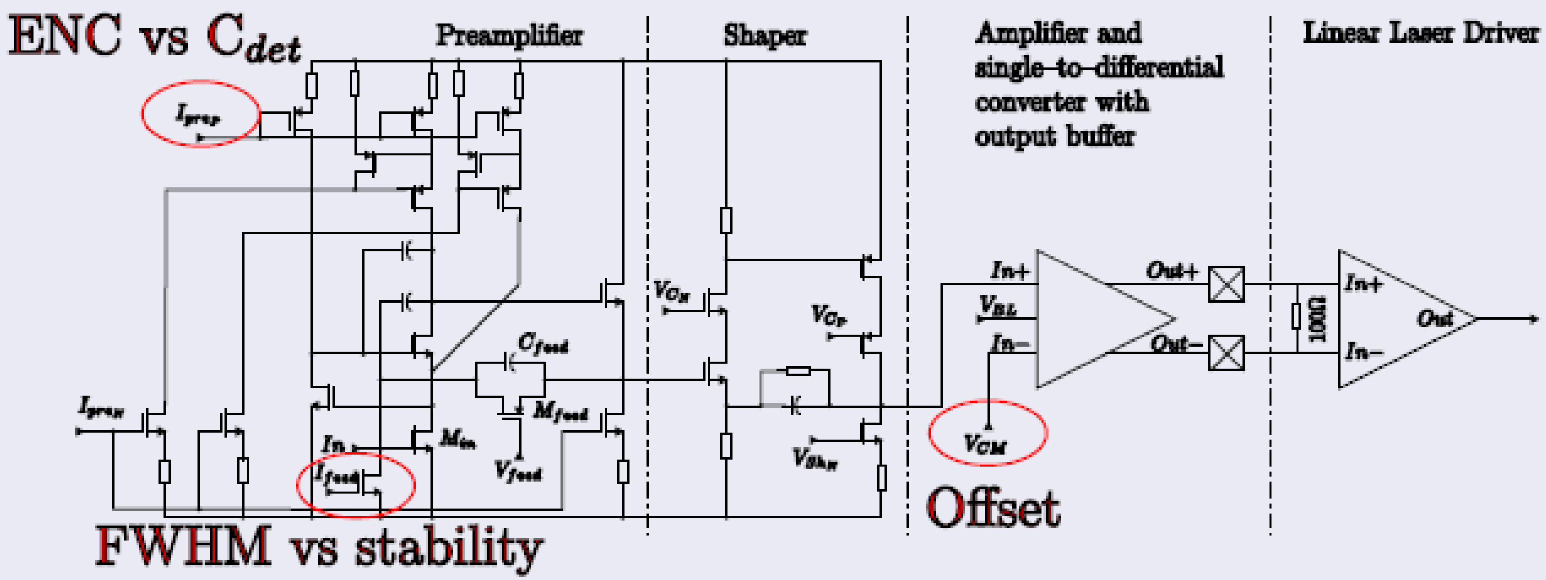
- Multi-amplitude test pulse to monitor linearity of response
- Laser diodes on carriage arm (lower radiation)
- Temperature sensor to account for optical response to temperature
    - Bragg grating: wavelength of transmitted light sensitive to temperature changes
- Temperature stabilization (other subsystems)





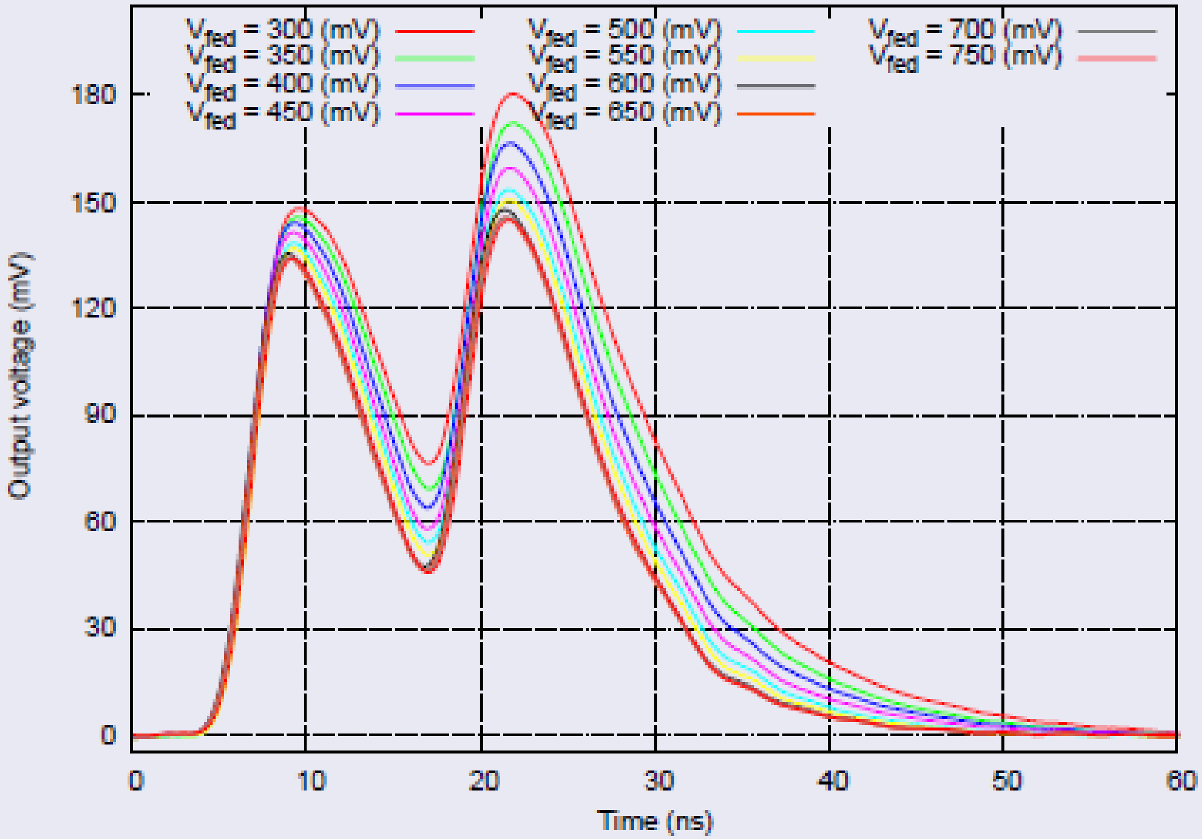
FE ASIC specs

Schematic diagram of BCM1FE channel

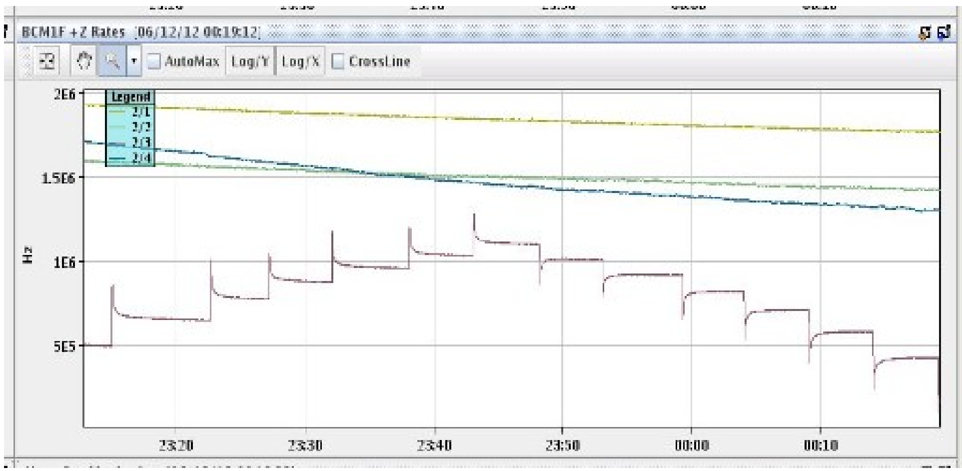


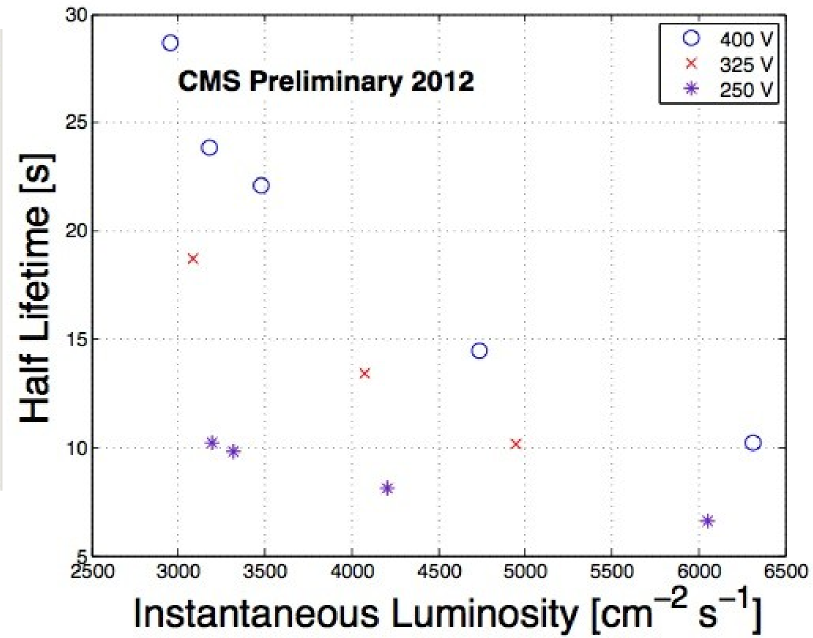
- IBM CMOS8RF 130nm technology
- 2.5 V power supply (high voltage enabled design)
- Power consumption ∼ 11 mW/ch (10mW of output buffer)

Distinguishability of MIPs wi 12.5 ns interval



Effects of Radiation: Diamond Sensors



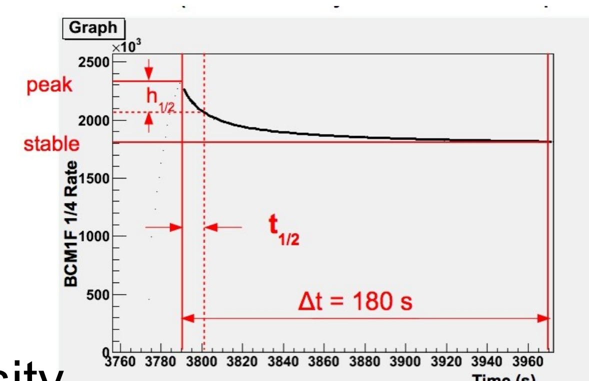


Polarization → Inefficiency, changes with time

Change in response depends on HV, luminosity

Ongoing investigation

– Recent study: thinning diamond appeared to improve polarization, more study needed



Important to characterize systematic error on luminosity calibration (TIE IN SLIDE WITH DIAMOND STUFF)

Improving Timing Performance: Discrimination

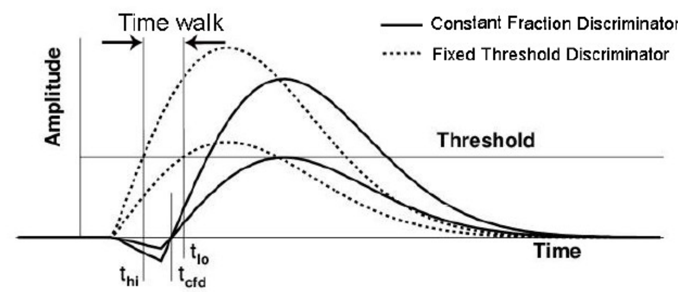
Current discriminator: CAEN v258B fixed-threshold discriminator

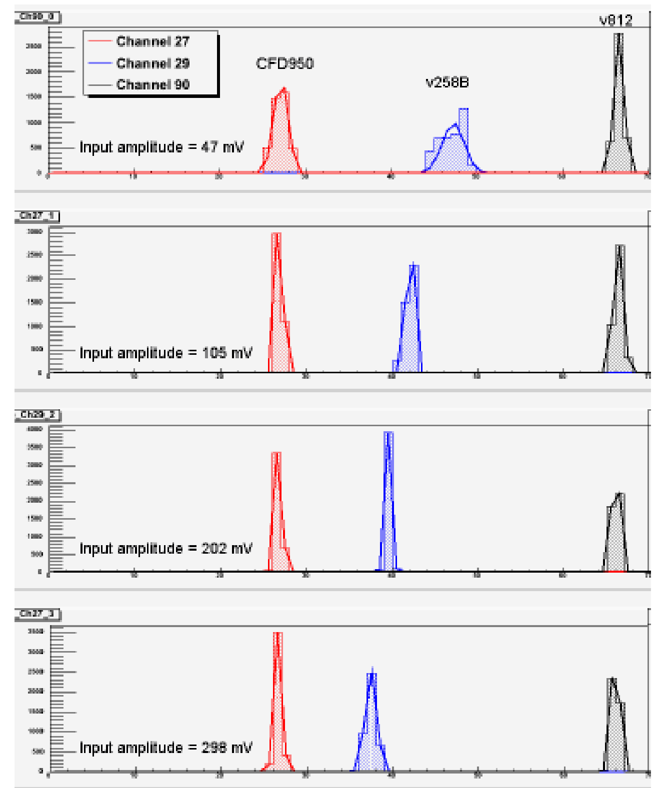
- Does not discriminate pulses closer than ~12 ns: deadtime causes loss of consecutive signals
- Triggers pulses of different amplitudes at different times: “time walk” ΔT ~12 ns

CFDs significantly improve on FTD time walk

- v812: better time resolution for trigger of single pulse
- CFD950: better resolution between consecutive pulses

(TIE IN WITH UPGRADED BACKEND SLIDE)





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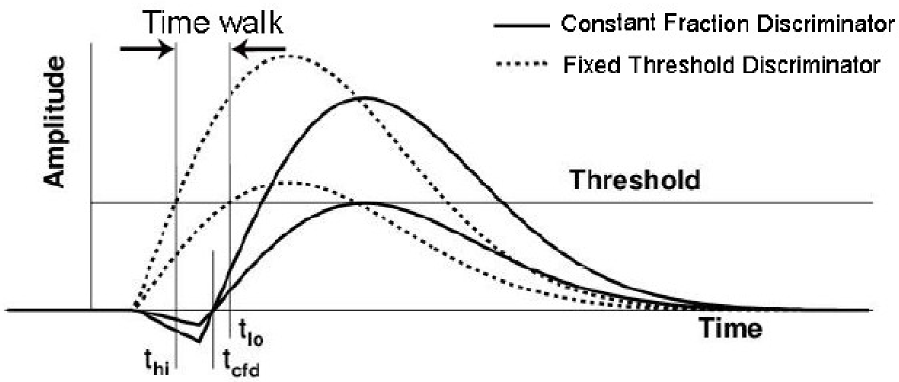
- Does not discriminate pulses closer than ~12 ns: deadtime causes loss of consecutive signals
- Triggers pulses of different amplitudes at different times: “time walk” ΔT ~12 ns

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



Upgrading Back End Electronics

Two parallel tracks

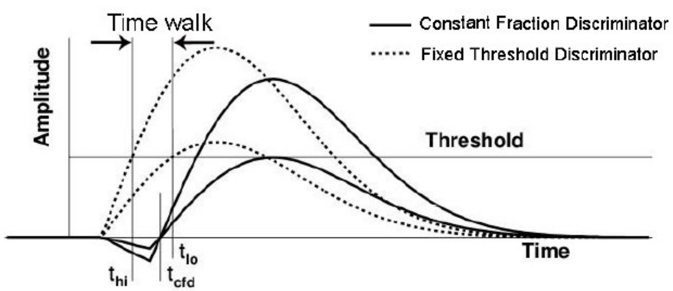
Make this slide mostly digitizer

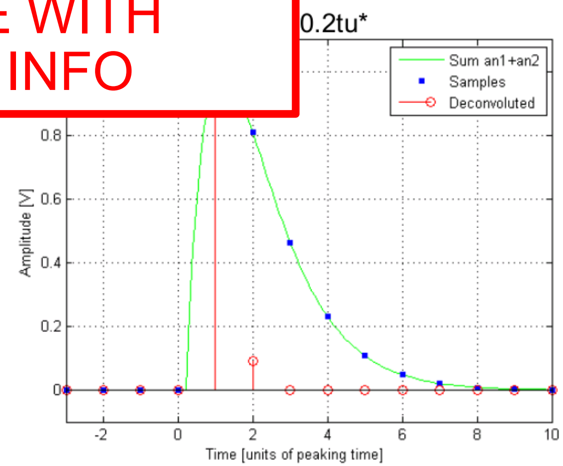
UPDATE WITH NEW INFO

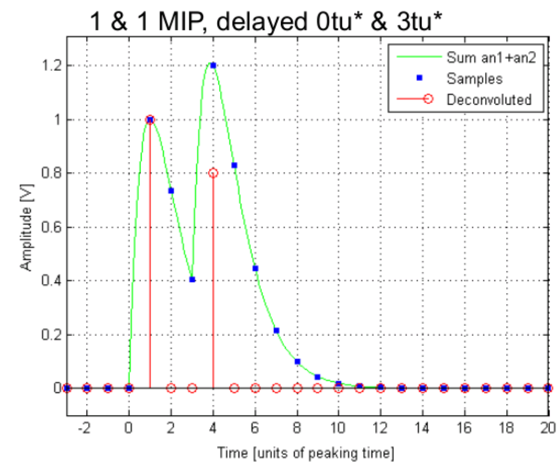
Discriminator path

ith fast peak-finding algorithms

Fixed-threshold vs. co fraction







*tu – time units

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

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

Development of algorithms ongoing

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

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 Monitor

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

Need this??? Lots of words, no pictures!

Comparison to Other Subdetectors

Compare bunch-by-bunch measured beam width to that measured by other luminosity subdetectors

Agreement within 1% on average