CMS

Diamond-based Systems in CMS: the BCM and PLT

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Outline

- Diamond properties
- BCM overview
  - BCM1F
  - BCM1L
  - BCM2L
- BCM Performance in 2011
- PLT overview
- PLT Design
- PLT test beam results
- Pilot PLT installation on Castor table

Why diamond?

Material properties

	Si	Diamond
Band gap [eV]	1.12	5.45
electron mobility [cm²/Vs]	1450	2200
hole mobility [cm²/Vs]	500	1600
Saturation velocity [cm/s]	0.8×10^7	2×10^7
Breakdown field [V/m]	3×10^5	2.2×10^7
Resistivity [Ω cm]	2×10^5	$>10^{13}$
Dielectric constant	11.9	5.7
Displacement energy [eV]	13-20	43
e-h creation energy [eV]	3.6	13
Ave e-h pairs per MIP per μm	89	36
Charge coll. dist. [μm]	full	~250
Thermal conductivity [W/cm·K]	1.5	22

Low $I_{leakage}$, shot noise (Band gap)

faster signal (electron mobility, hole mobility, saturation velocity)

Low capacitance, noise (Dielectric constant)

High radiation hardness (Displacement energy)

Smaller signal (e-h creation energy, e-h pairs per MIP, charge collection distance)

Full in SC diamond (Charge coll. dist.)

no localized hot spots no need for cooling (Thermal conductivity)

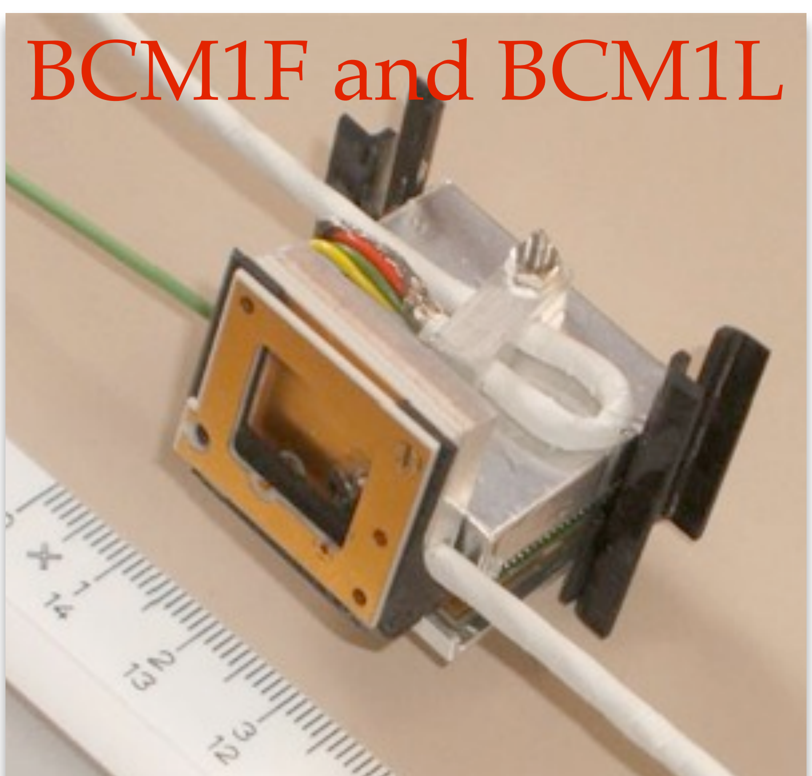
Why diamond?

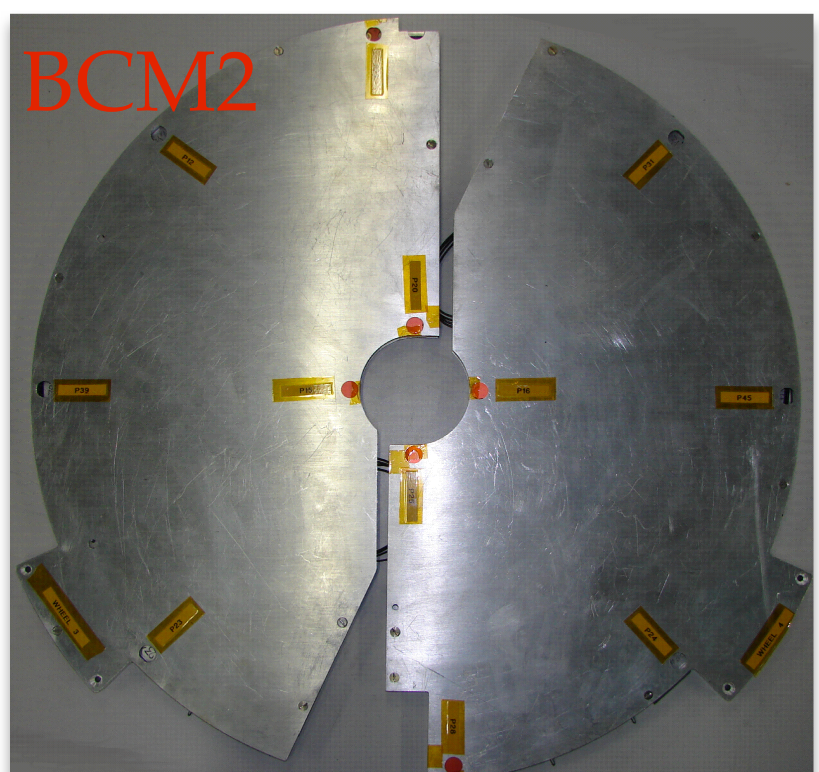
Potential application

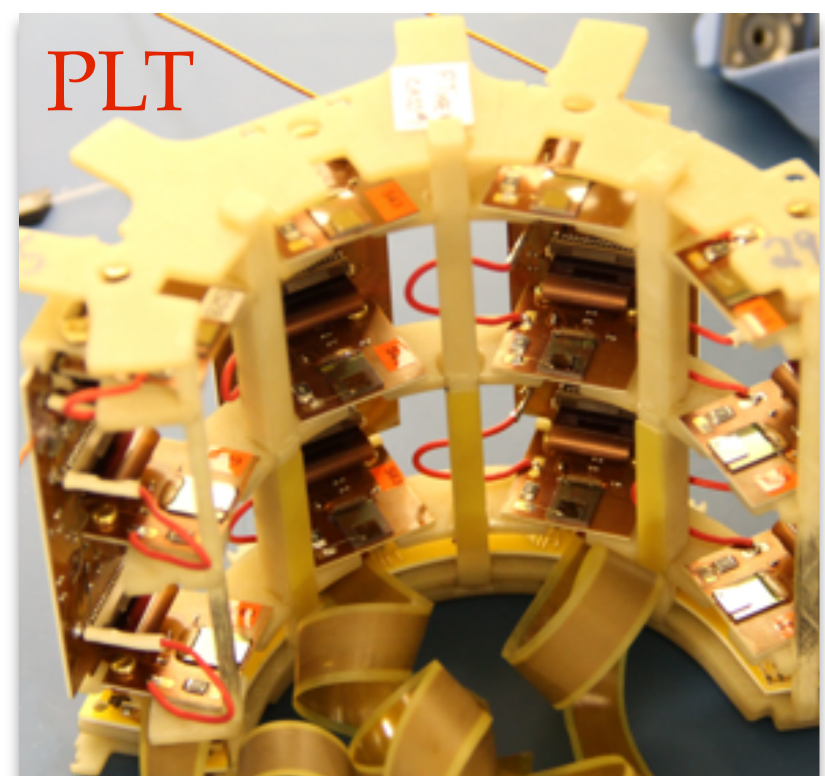
- Beam Condition Monitors
  - Radiation hardness - can be used close to beam line
  - Low noise - reliable operation
  - Faster signal - faster beam aborts
- Inner layer tracking
  - At SLHC (~5 x 10^{34}/cm^2/s) inner tracking layers receive fluence in excess of Φ_{eq}~2 x 10^{15}/cm^2/yr
    - Silicon based tracker maybe work up to ~10^{15}/cm^2 (charge trapping)
    - Diamond loses only 15% of signal after 2 x 10^{15}/cm2
    - Leakage current decreases with fluence
    - Resolution improves - irradiated diamond appears more ‘uniform’
  - No need for cooling - less infrastructure material

Diamond sensor based systems in CMS

- BCM1F
  - ➡ Fast beam current monitor, time resolution ~ ns
- BCM1L, BCM2
  - ➡ Slow beam current monitors, time resolution 40 μs
- PLT
  - ➡ Luminosity monitor based on single crystal diamonds







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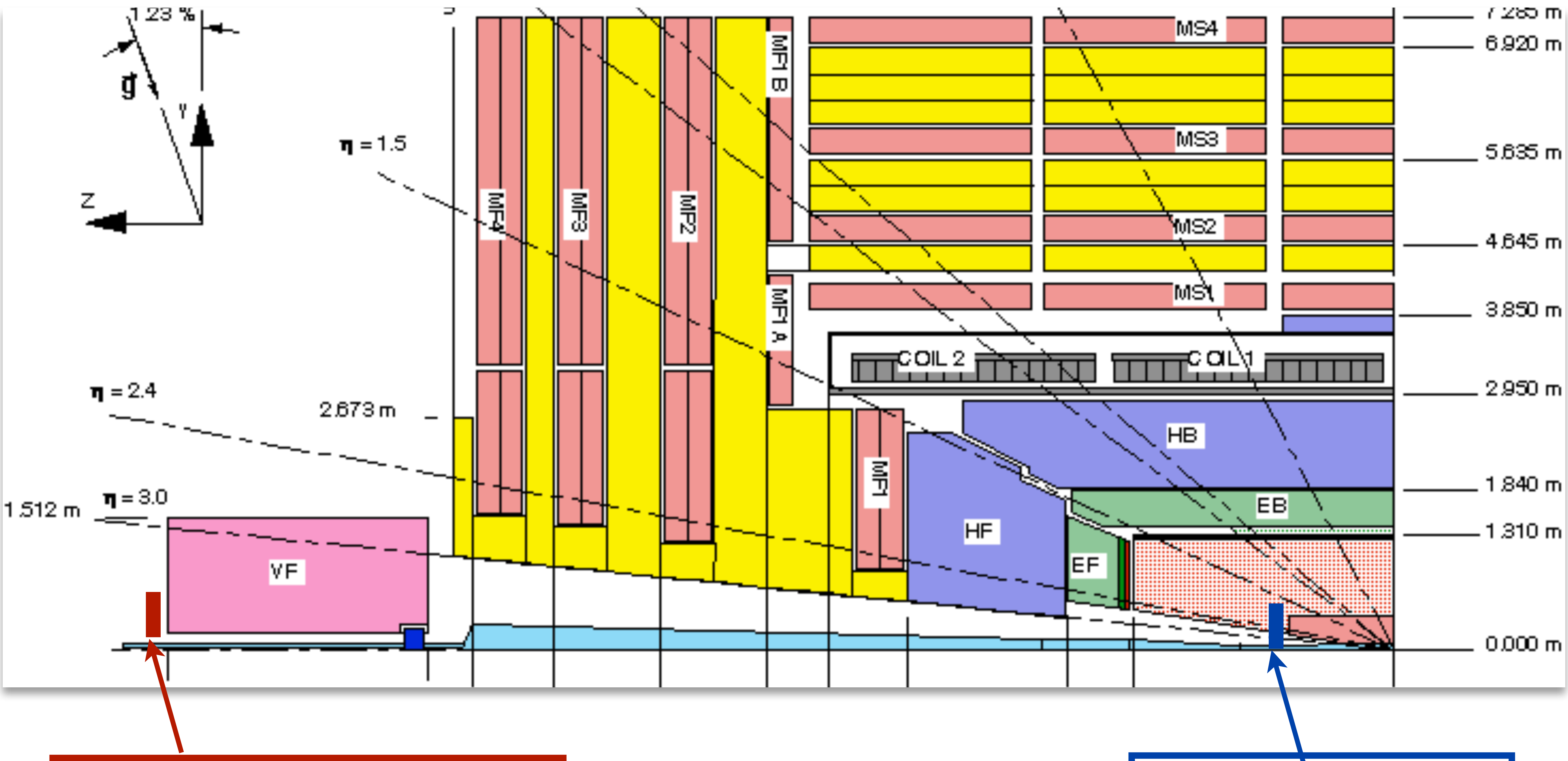
Location of BCM1, 2 and PLT



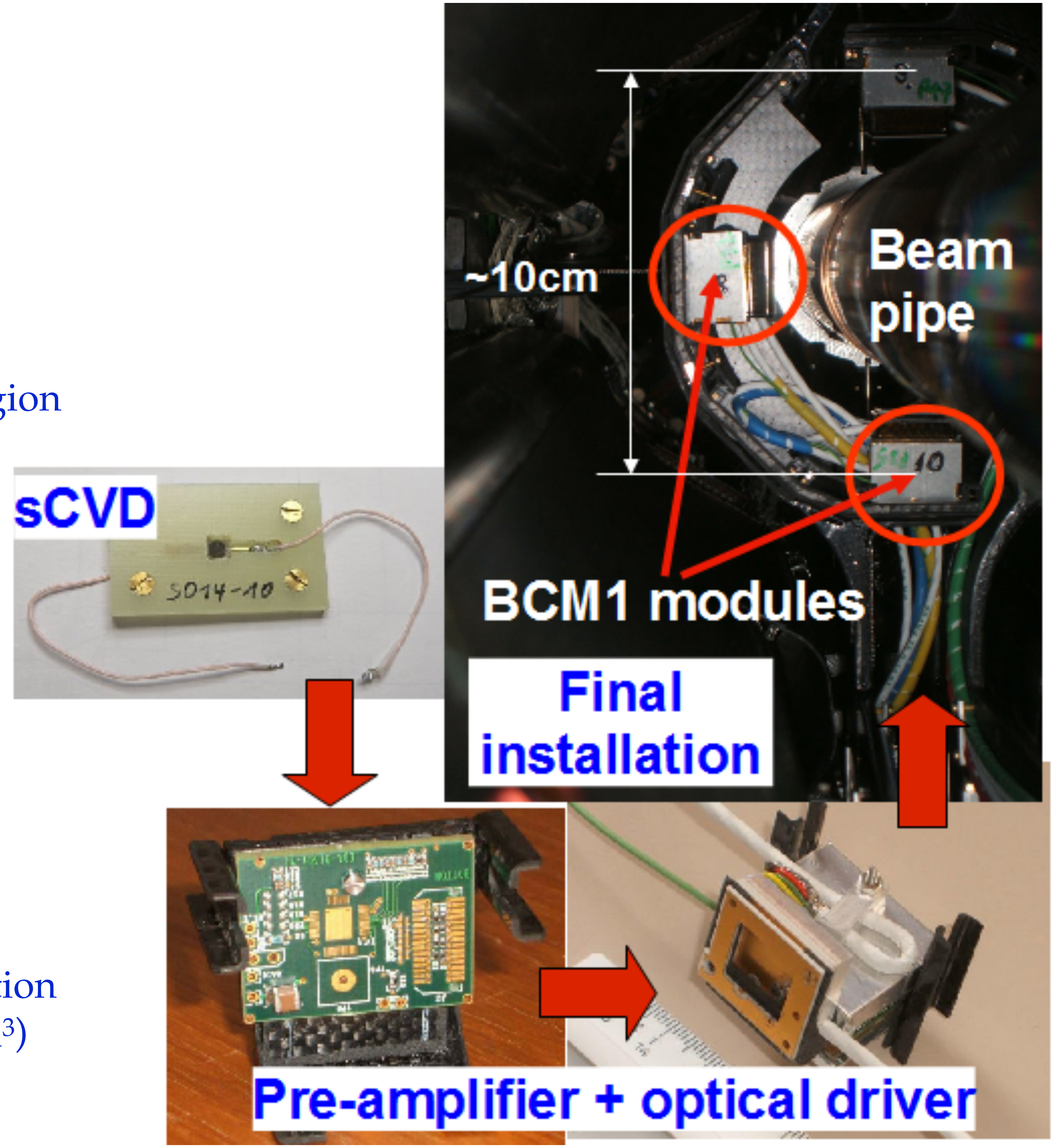
z ~15 m
BCM2: r~5 cm, 29 cm
PLT pilot location: r ~ 5 cm

z~1.8 m, r~5 cm
BCM1F, BCM1L,
PLT design location

Fast Beam Conditions Monitor BCM1F: Overview

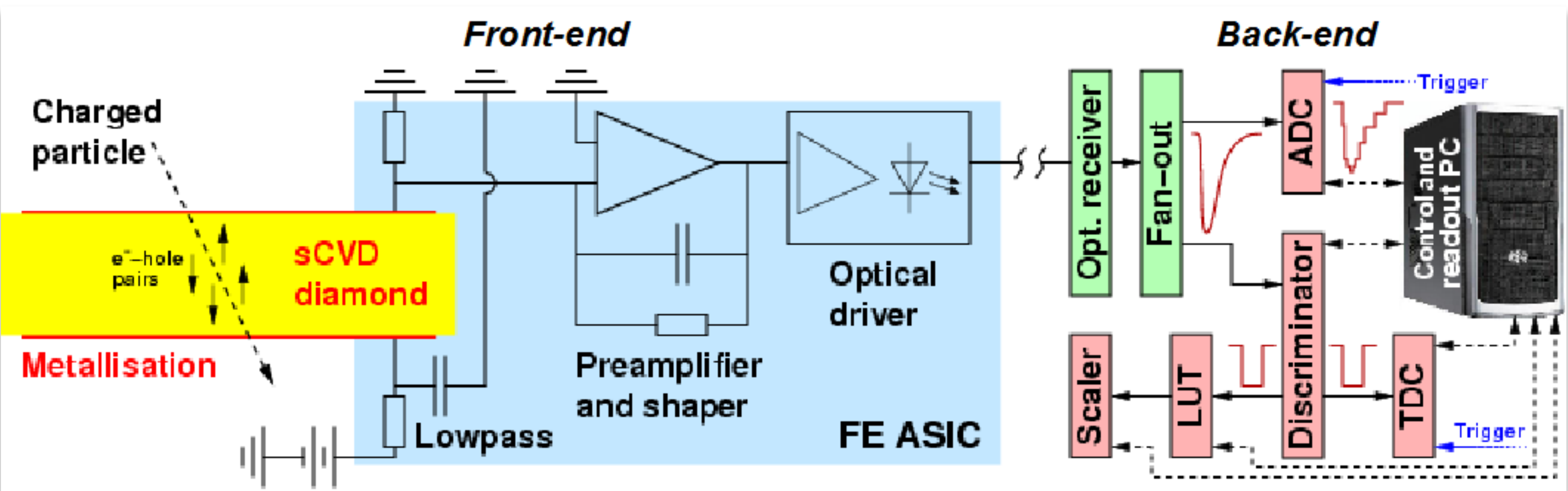
Particle detector with nanosecond time resolution measuring the beam halo particles, beam-gas interactions, and collision products.

- Tasks
  - Monitoring and protection
  - Report total flux in the inner detector region to LHC (BKGD1)
  - Report beam halo flux to LHC (BKGD2)
  - Report instant luminosity to CMS
- Requirements:
  - Detection of MIPs
  - Low power and radiation hardness
- Design:
  - 4 Single Crystal Chemical Vapor Deposition (sCVD) diamond sensors (5 x 5 x 0.5 mm^3) in 4 modules at Z = 1.8 m (~6.25 ns) on both sides of the CMS IP, r < 5 cm



Fast Beam Conditions Monitor BCM1F: DAQ Chain

- Front-end:
  - Single Crystal CVD diamond sensors operate as solid state ionization chambers.
  - A charge sensitive pre-amplifier collects the induced charges and shapes a proportional signal that is transmitted to the counting room as analog optical signal.
- Back-end:
  - The optical signal is converted into electrical signal and is processed and stored independently of the CMS DAQ framework.
  - The main data-acquisition devices are: scalers, ADCs, TDCs and LUT (FPGA)



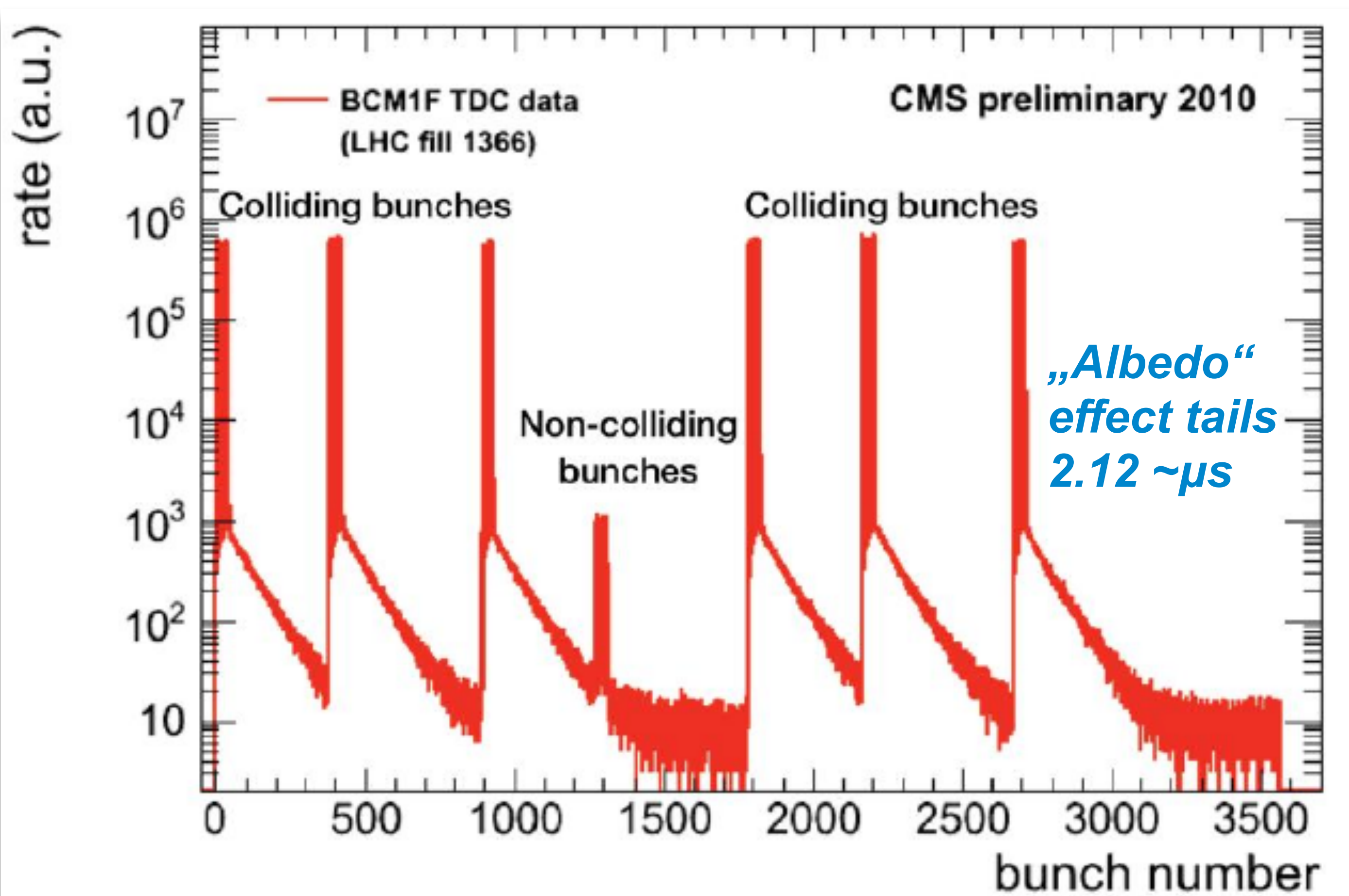
Courtesy of CMS BRM group

Fast Beam Conditions Monitor BCM1F: TDC Results

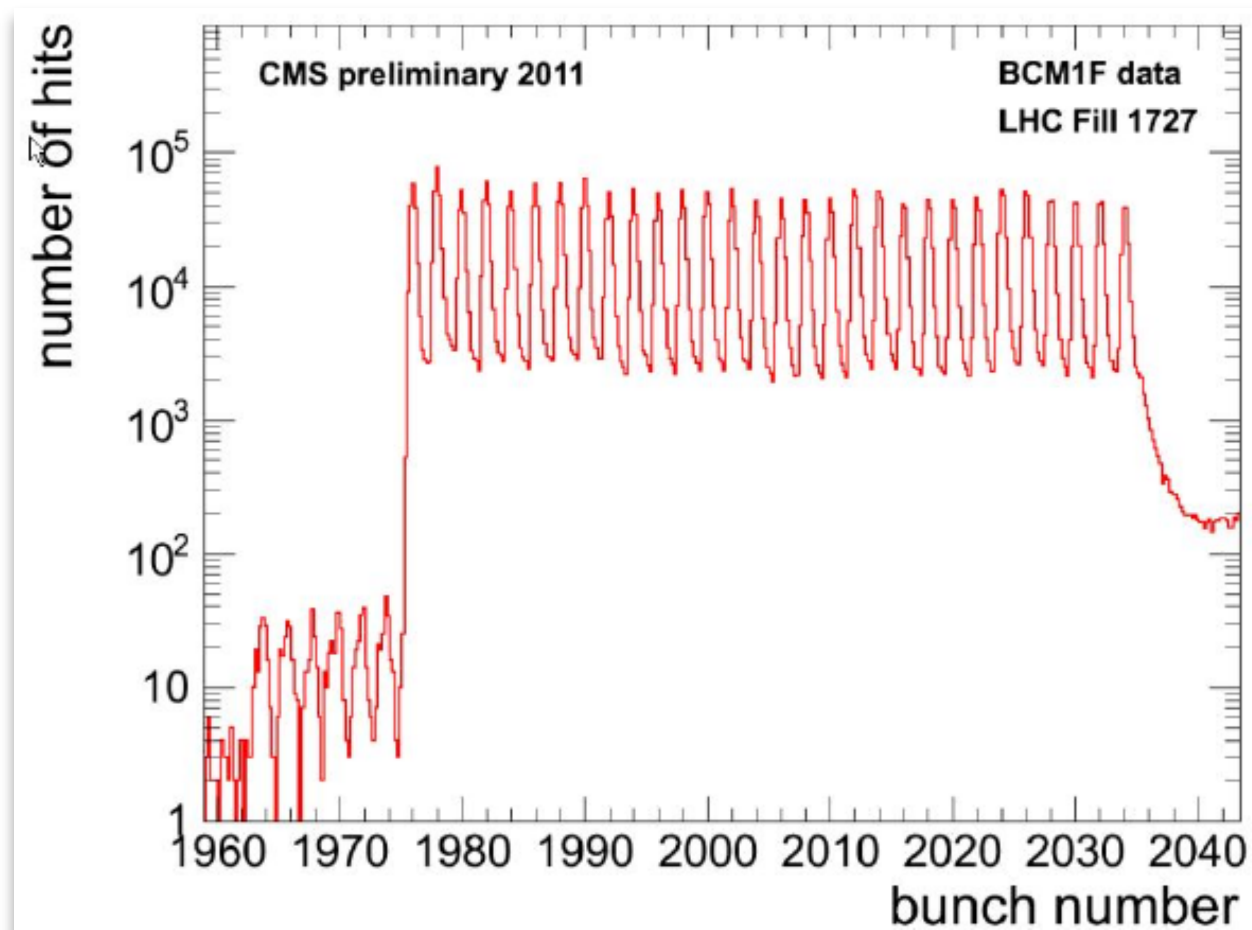
- Discriminated sensor signals are time digitized by a multi-hit TDC board with 0.8 ns resolution using the LHC orbit as reference.
- Using the arrival time distribution of the hits, the bunch number identification is done and forwarded to the CMS control room:

$$BN = \frac{t_{TDC} - 6290}{24.95} + 1$$

Bunch ID plot



Zoom in 50 ns bunches



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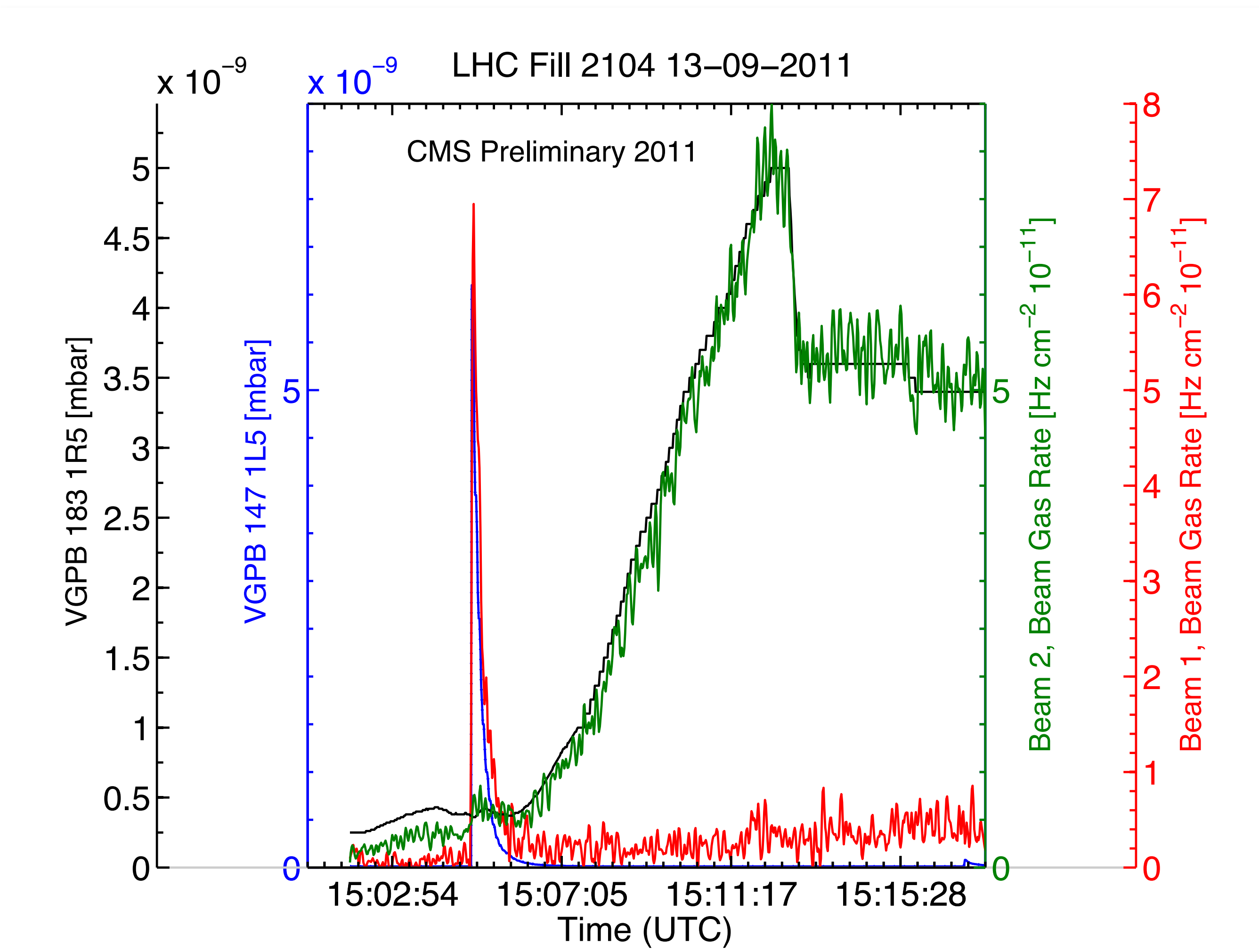
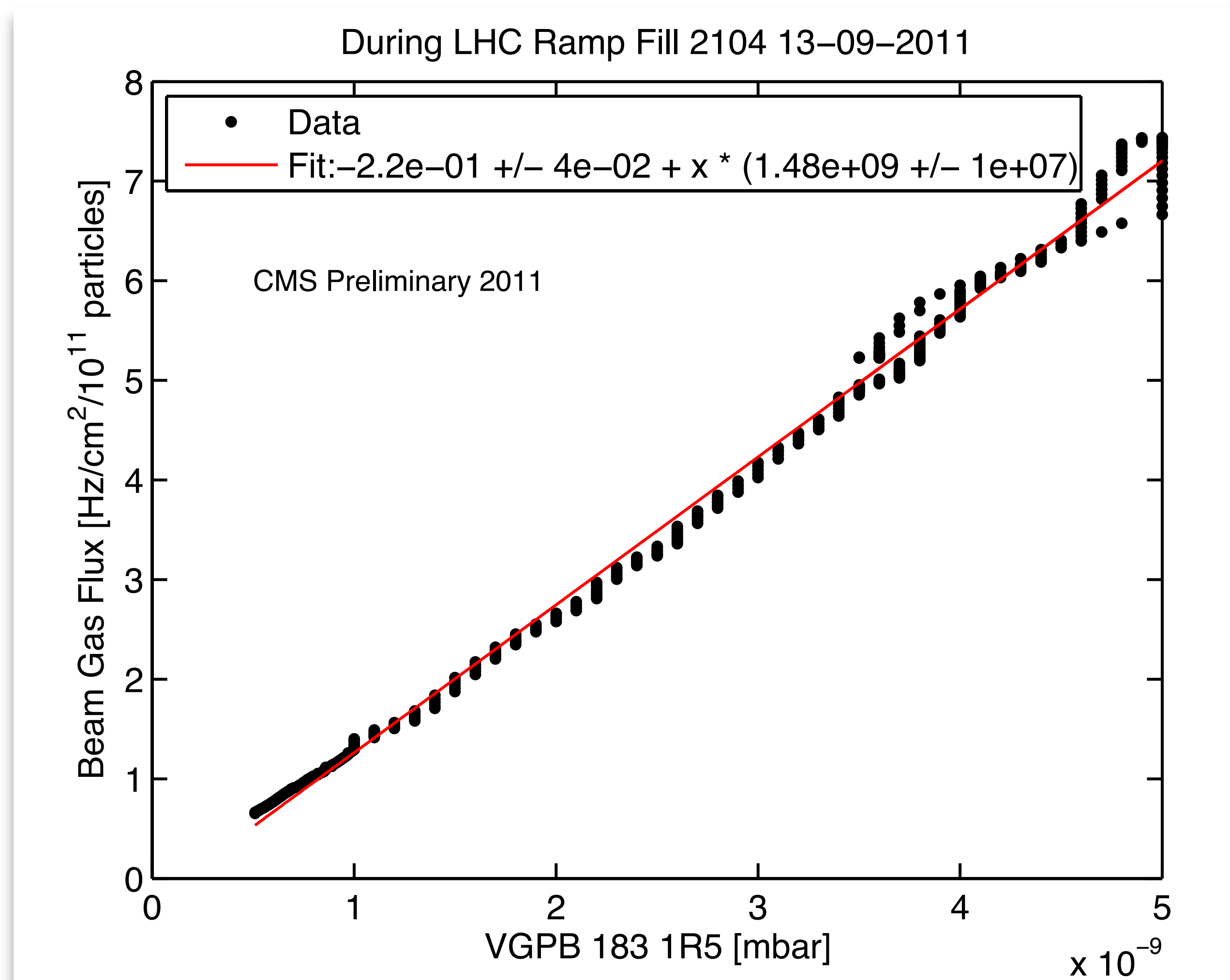
Fast Beam Conditions Monitor BCM1F: Beam gas rate monitoring

- For beam 1, measure signal in BCM1F Z+ and BCM1F Z- (12.5 ns later)
- For beam 2, measure signal in BCM1F Z- and BCM1F Z+ (12.5 ns later)
    - ➡ Observe linear correlation between vacuum deterioration and corresponding BCM1F signal
    - ➡ can be used to veto on beam gas events





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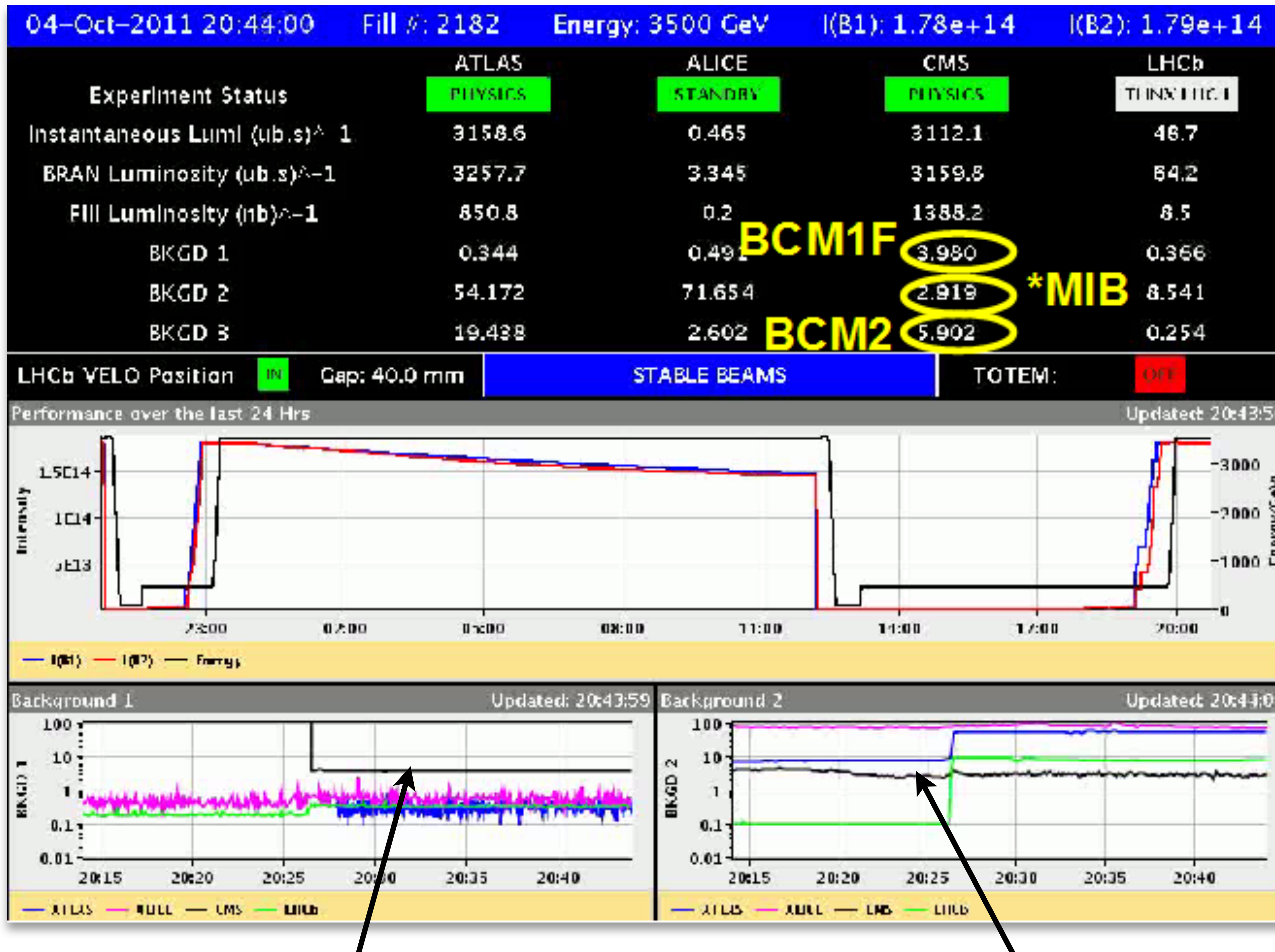
Fast Beam Conditions Monitor BCM1F: Results

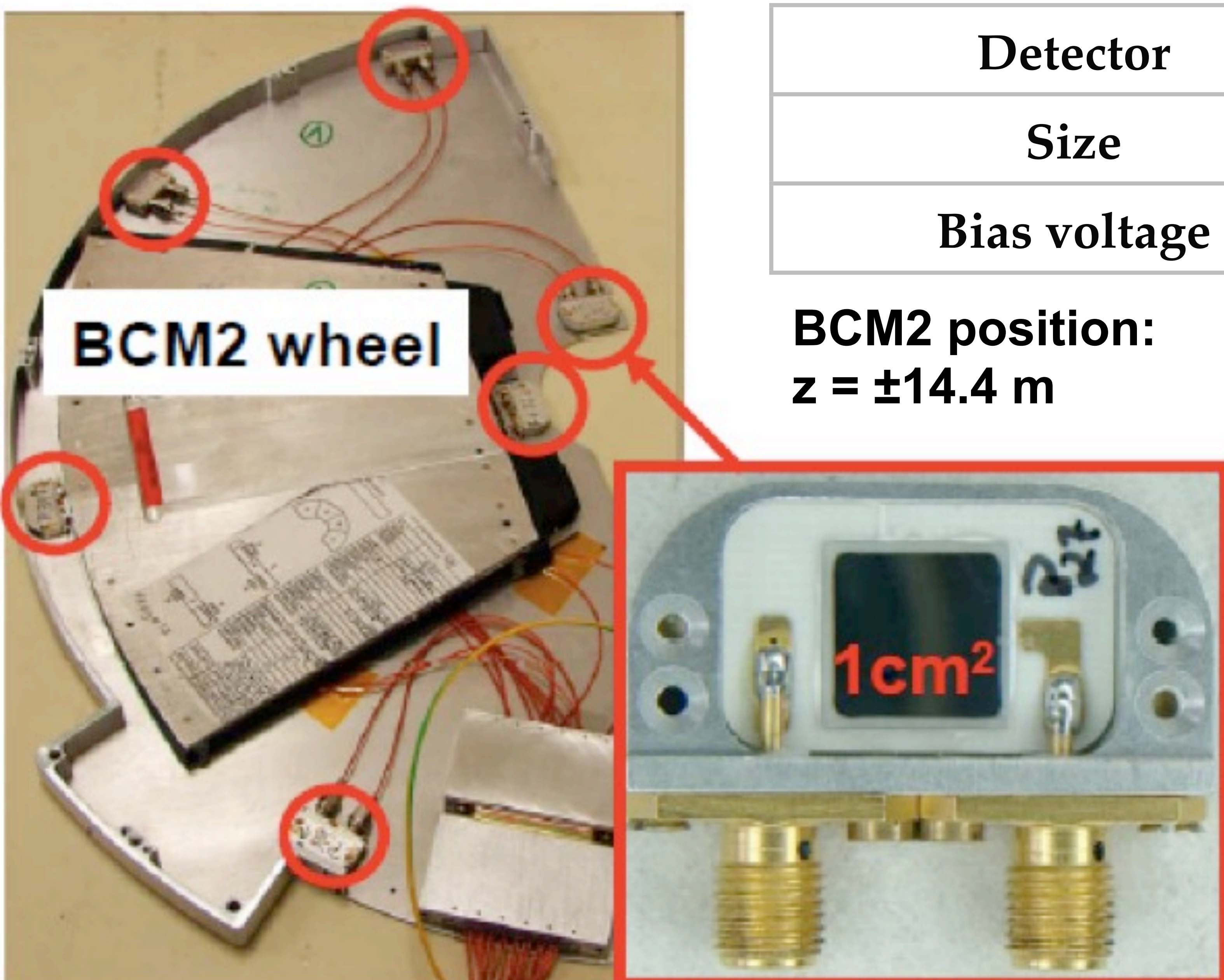
- All measurements are available in the CMS control room.
- Published background numbers indicate normal/safe operation.
- Based on these numbers pixel and tracker decide in the beginning of a fill if they will switch on their detectors.
- They are an indication to the LHC control room of the beam quality.



Background 1 **CMS in black** Background 2

Beam Conditions Monitor
BCM1L and BCM2: Overview

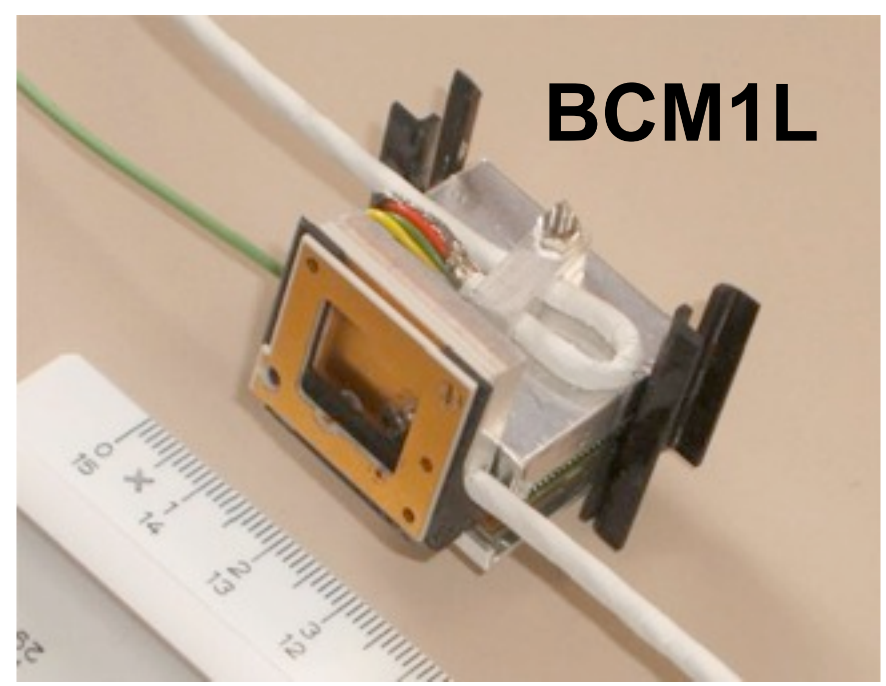
- Other parts of BCM system measure sensor current in diamonds.
- It is composed of two subsystems: BCM2 and BCM1L
- BCM2 can dump the beam in case the abort thresholds (set to protect Pixel and Tracker from too high particle fluxes) are reached.



Detector	32 pCVD
Size	10×10×0.4 mm3
Bias voltage	200V

BCM2 position:
z = ±14.4 m

BCM1L position:
z = ±1.8 m



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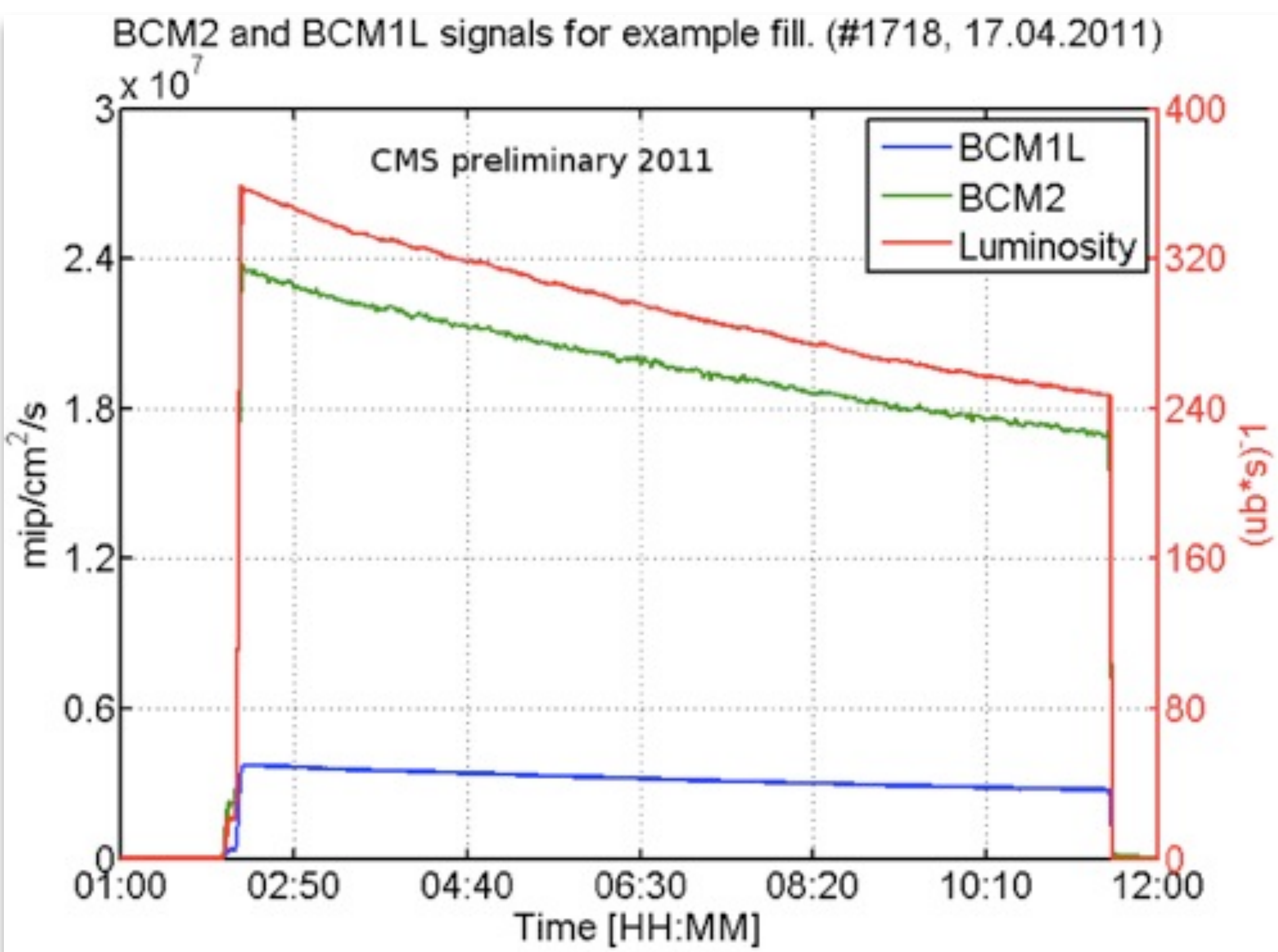
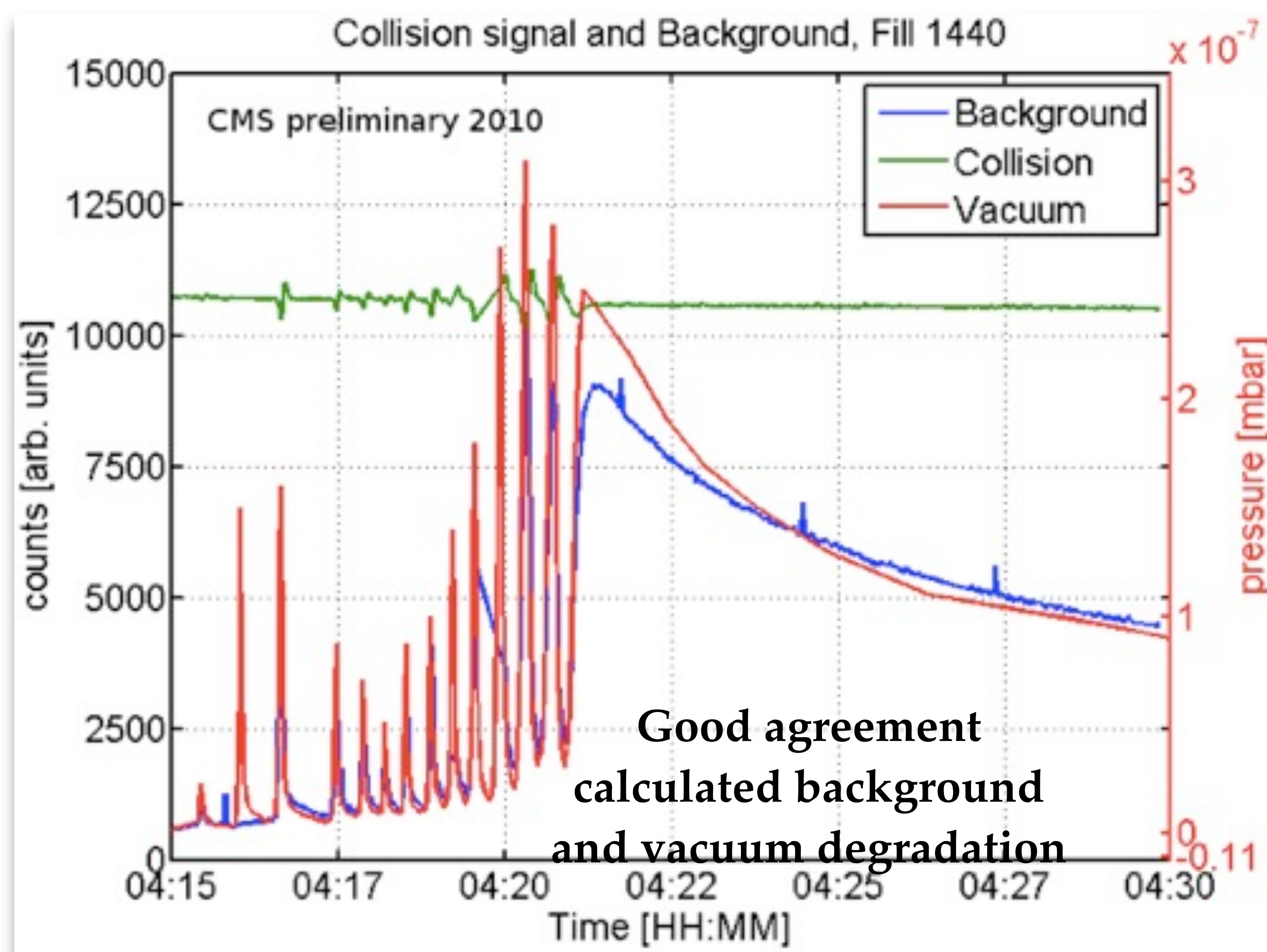
Beam Conditions Monitor BCM1L and BCM2: Results

- The BCM has been integrated into the LHC beam abort since the first running of the LHC.
- It delivers information about the beam conditions to CMS and LHC and can be used for monitoring of beam loss events at long and short time scales.

Typical signal current during a proton fill dominated by collision products



Background signal for the vacuum event follows the vacuum pressure change



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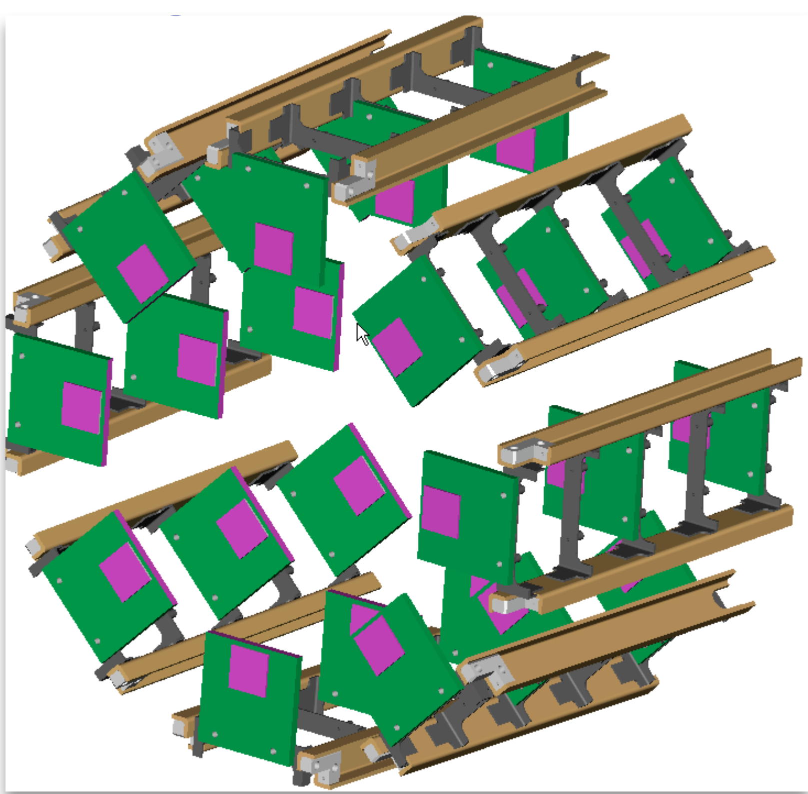
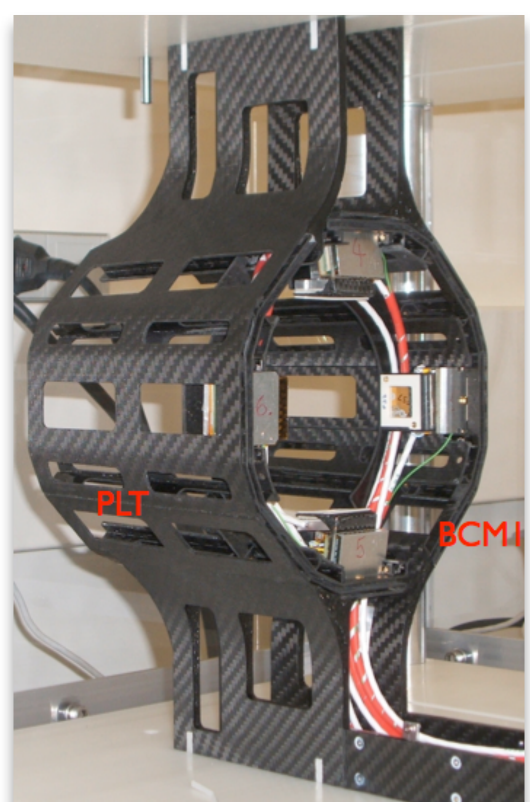
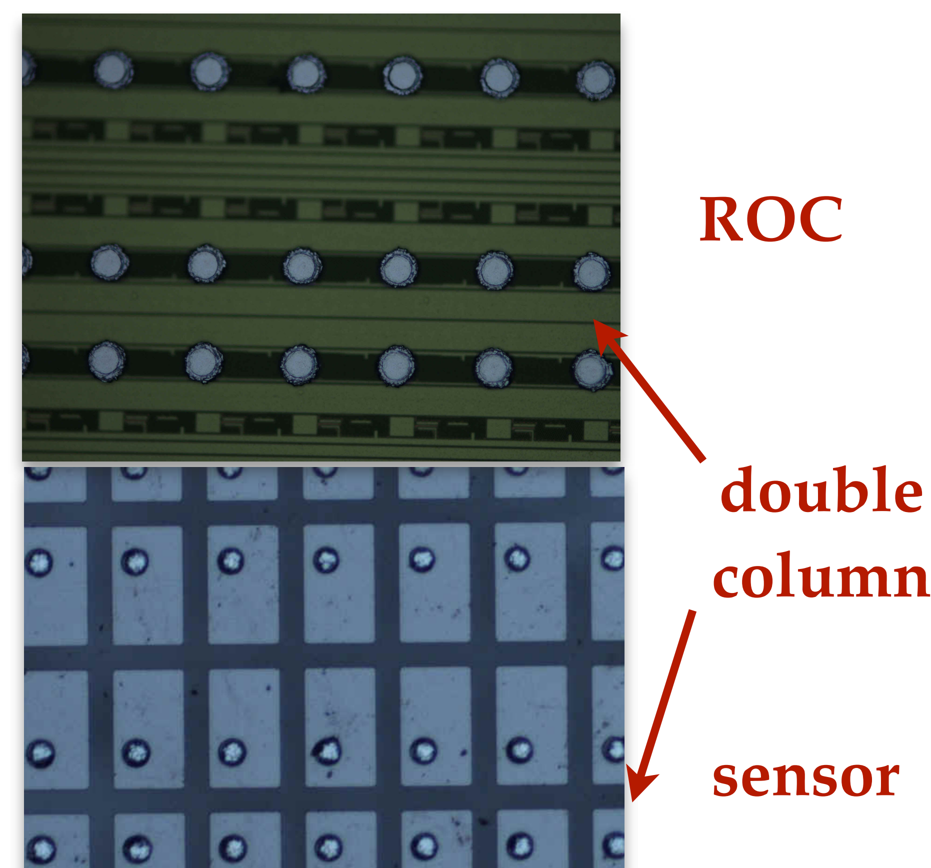
PLT: Overview

- Dedicated, stand–alone luminosity monitor
- Eight 3-plane telescopes each end of CMS
- 1.6^0 pointing angle and design position: r = 4.8 cm, z = 175 cm, $\eta \sim 4.2$, 7.5 cm long
  - ➡ shares carriage with BCM1
- Diamond pixel sensors pixel area: 3.9 mm x 3.9 mm
- Count 3-fold coincidences fast-or signals (40 MHz)
- Full pixel readout pixel address, pulse height (1 kHz)
- Stable 1% precision on bunch-by-bunch relative luminosity







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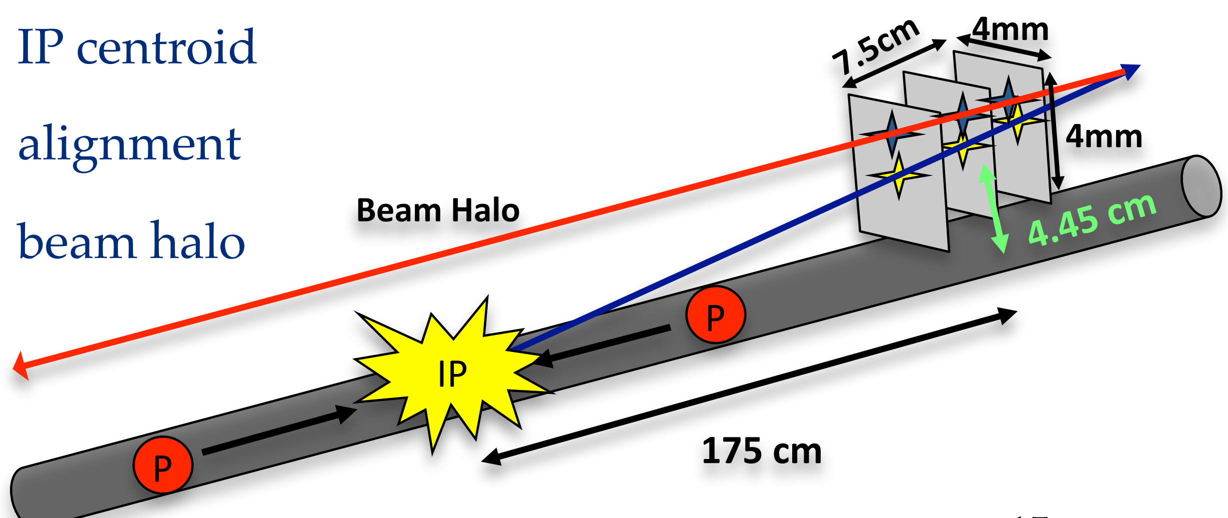
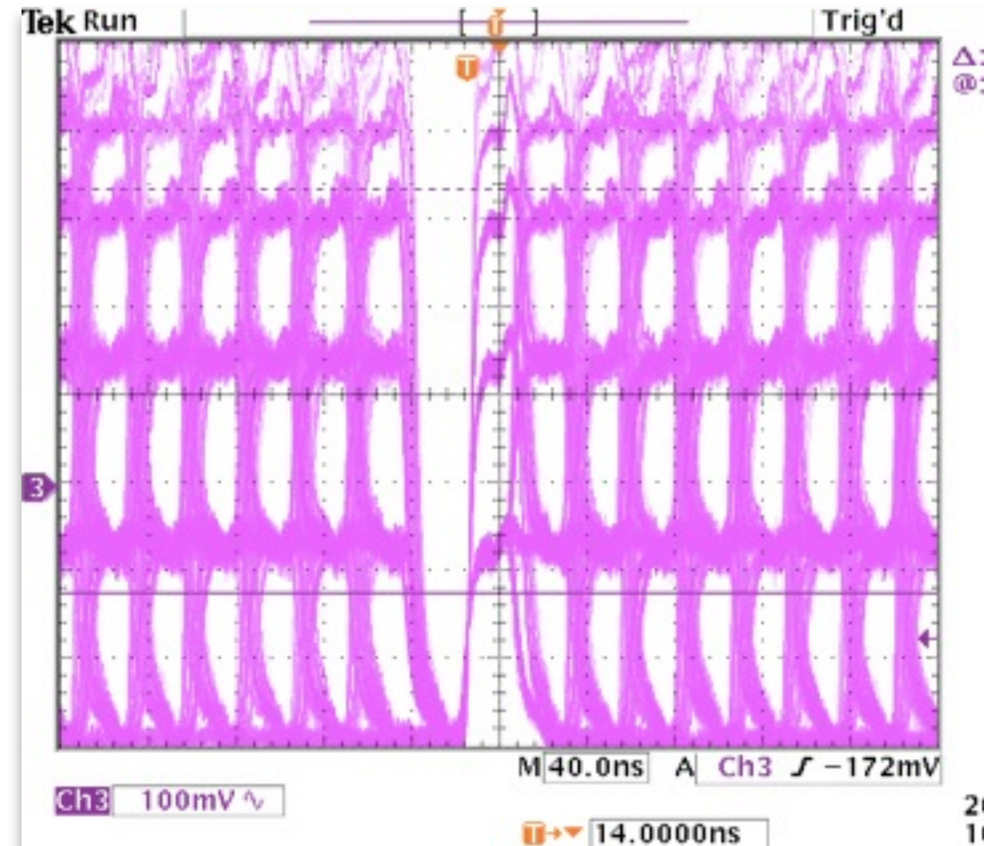
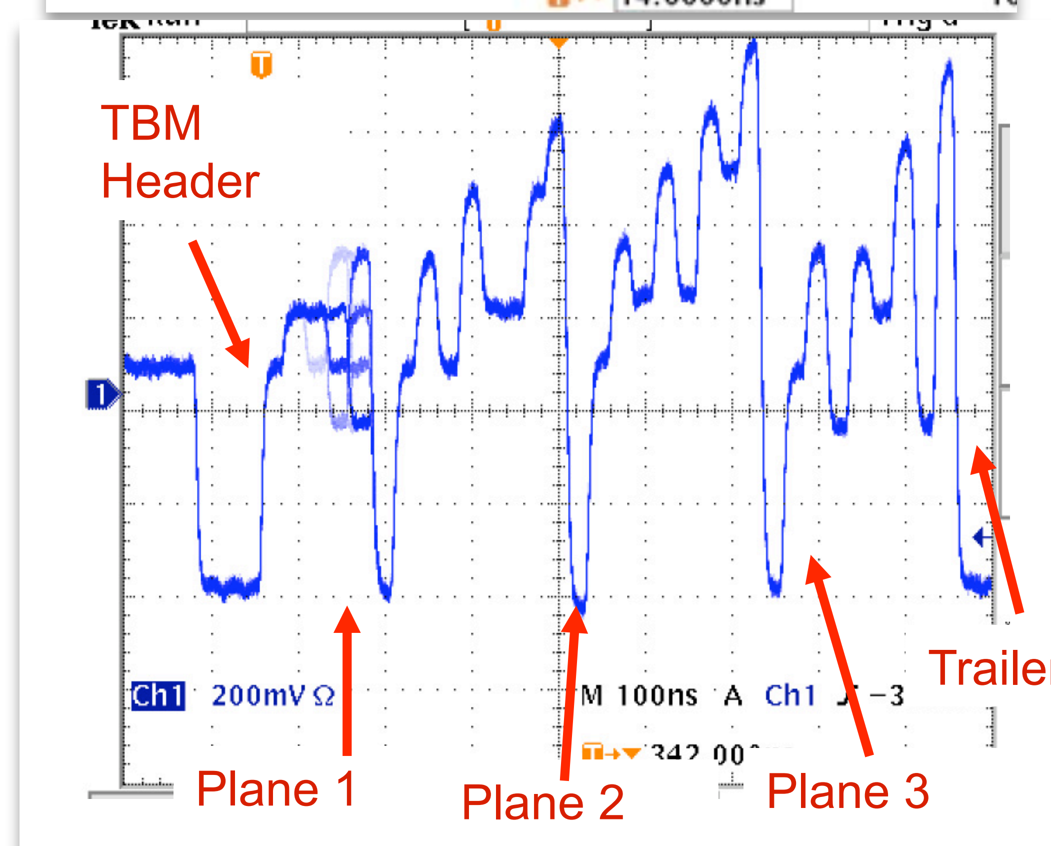
PLT: Hybrid readout

- FastOr readout
  - ➡ every bunch crossing (40 MHz)
  - ➡ level: number of double columns hit
  - ➡ bunch-by-bunch luminosity
  - ➡ abort gap particles
- Full pixel readout
  - ➡ 1kHz to 10 kHz rate
  - ➡ hit pixel addresses and pulse heights
  - ➡ powerful diagnostic
  - ➡ corrections for accidentals and overlaps
  - ➡ pixel efficiencies
  - ➡ bunch integrated luminosity
  - ➡ IP centroid
  - ➡ alignment
  - ➡ beam halo







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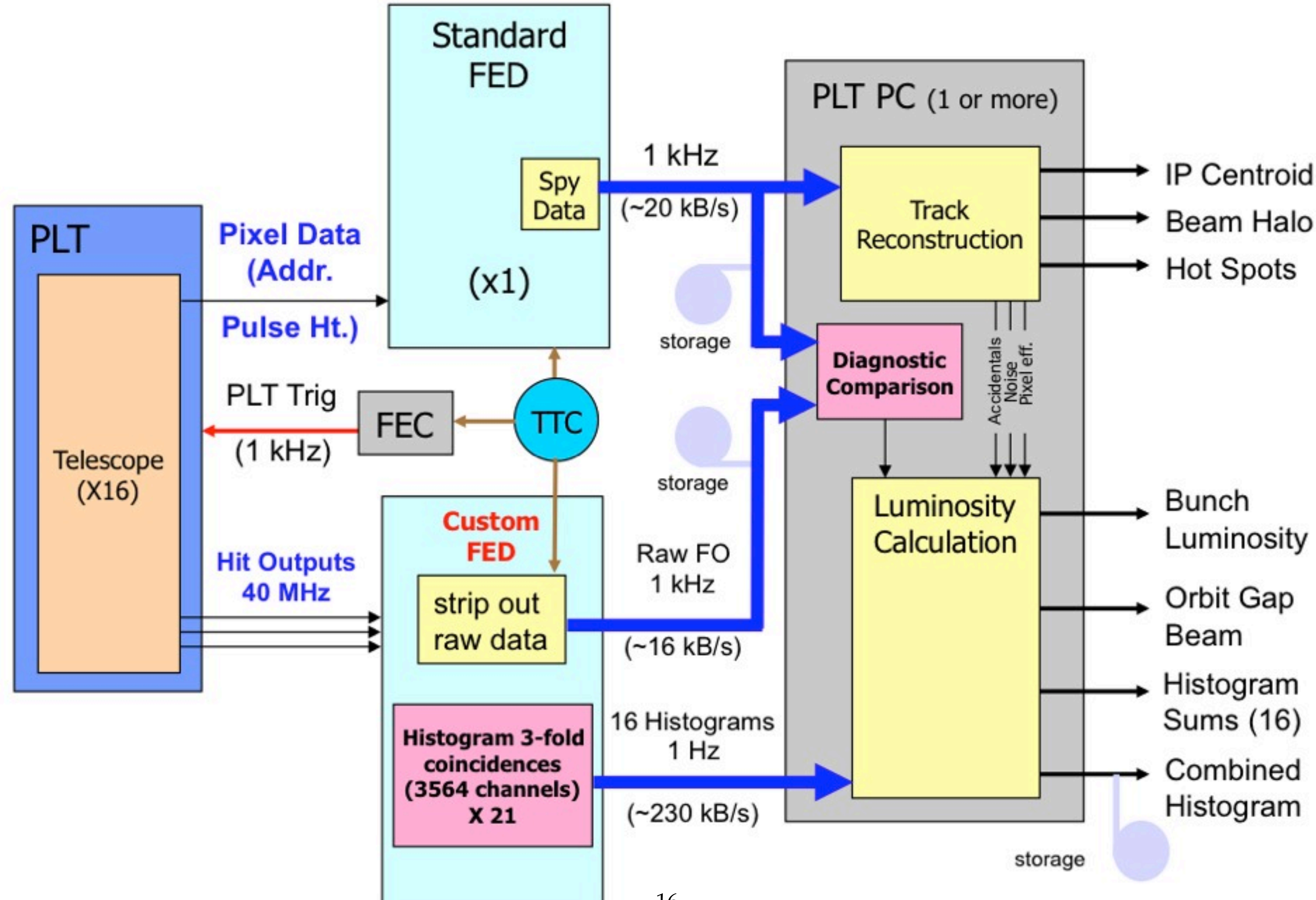
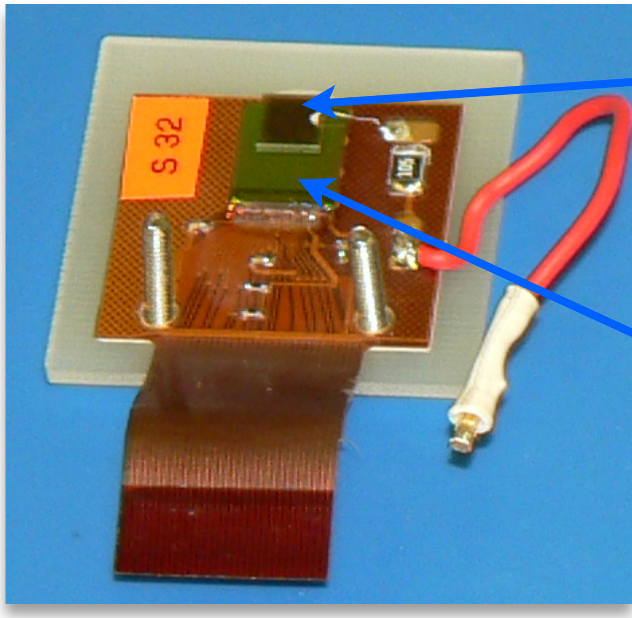
PLT:
Data Acquisition



PLT: Components

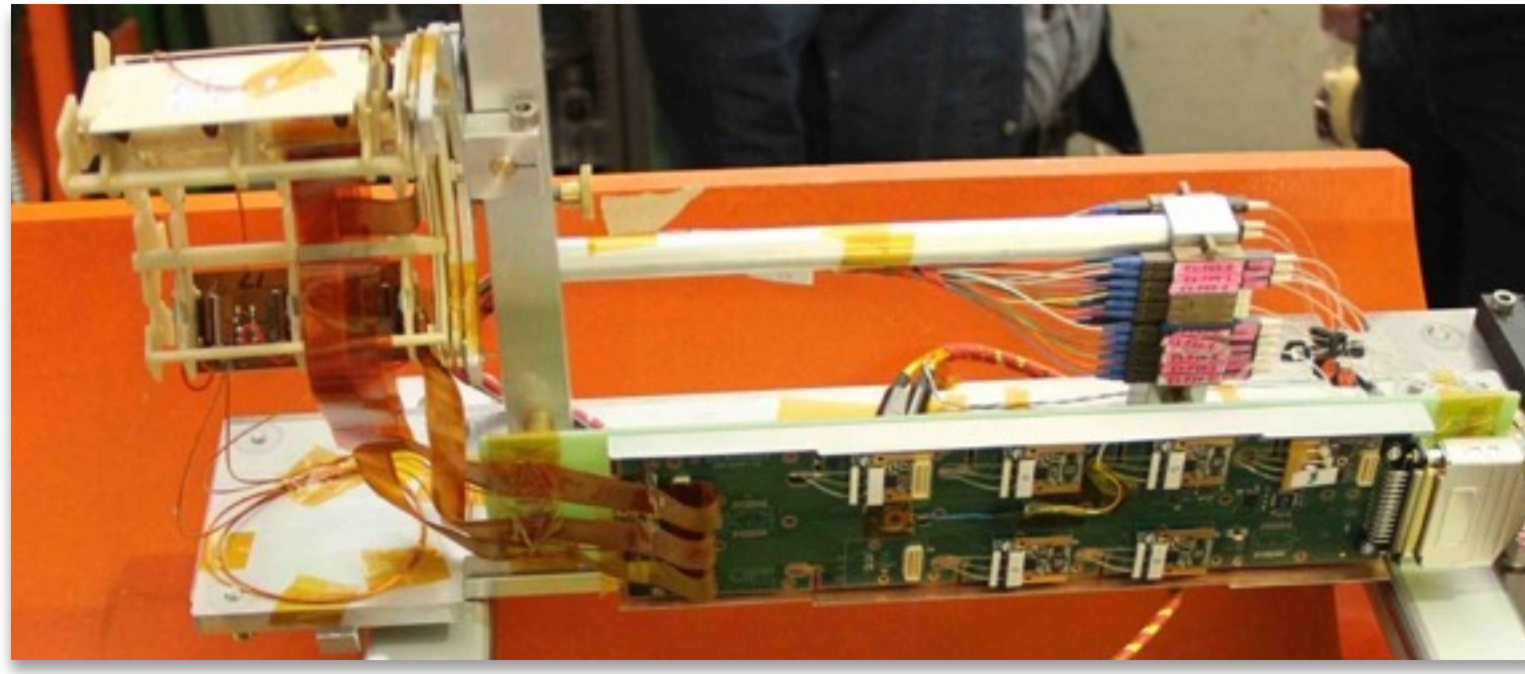
PLT Hybrid board



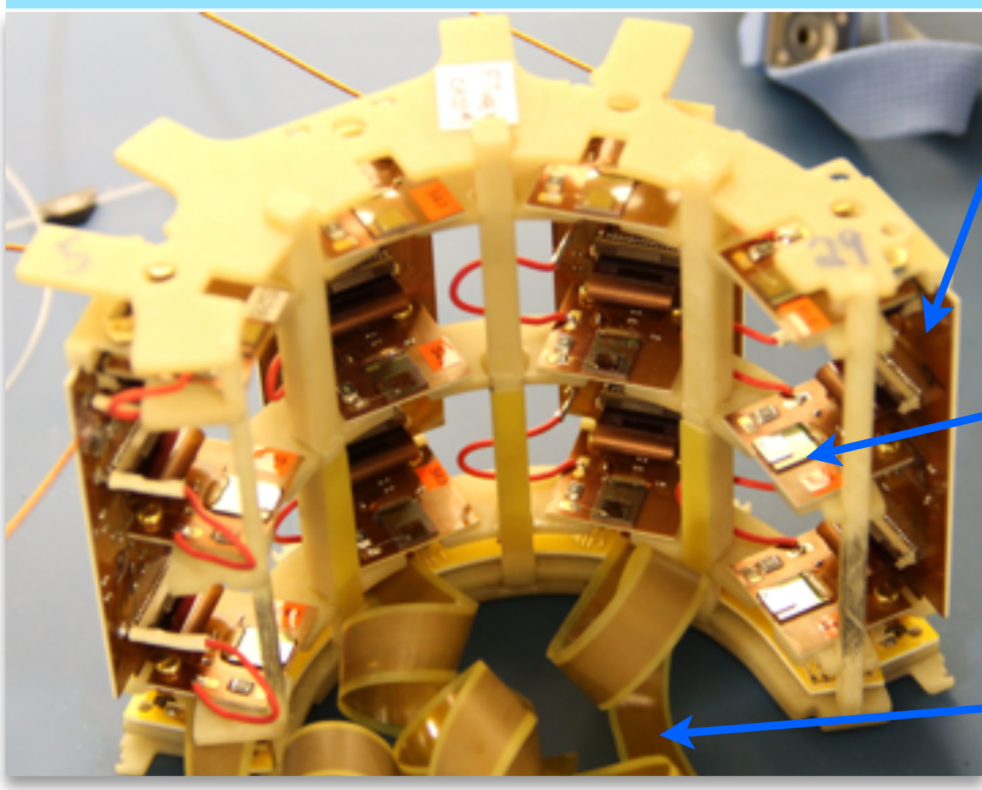
Diamond sensor

CMS pixel readout chip

Pilot PLT assembly



PLT Cassette

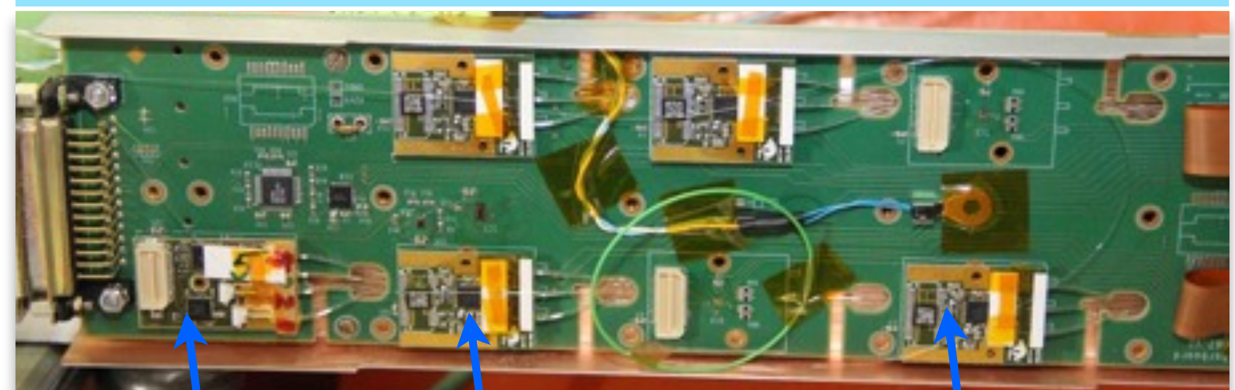


HDI

Hybrid with diamond sensor and readout chip

Flexi-cables to the opto-board

opto-board



DOH

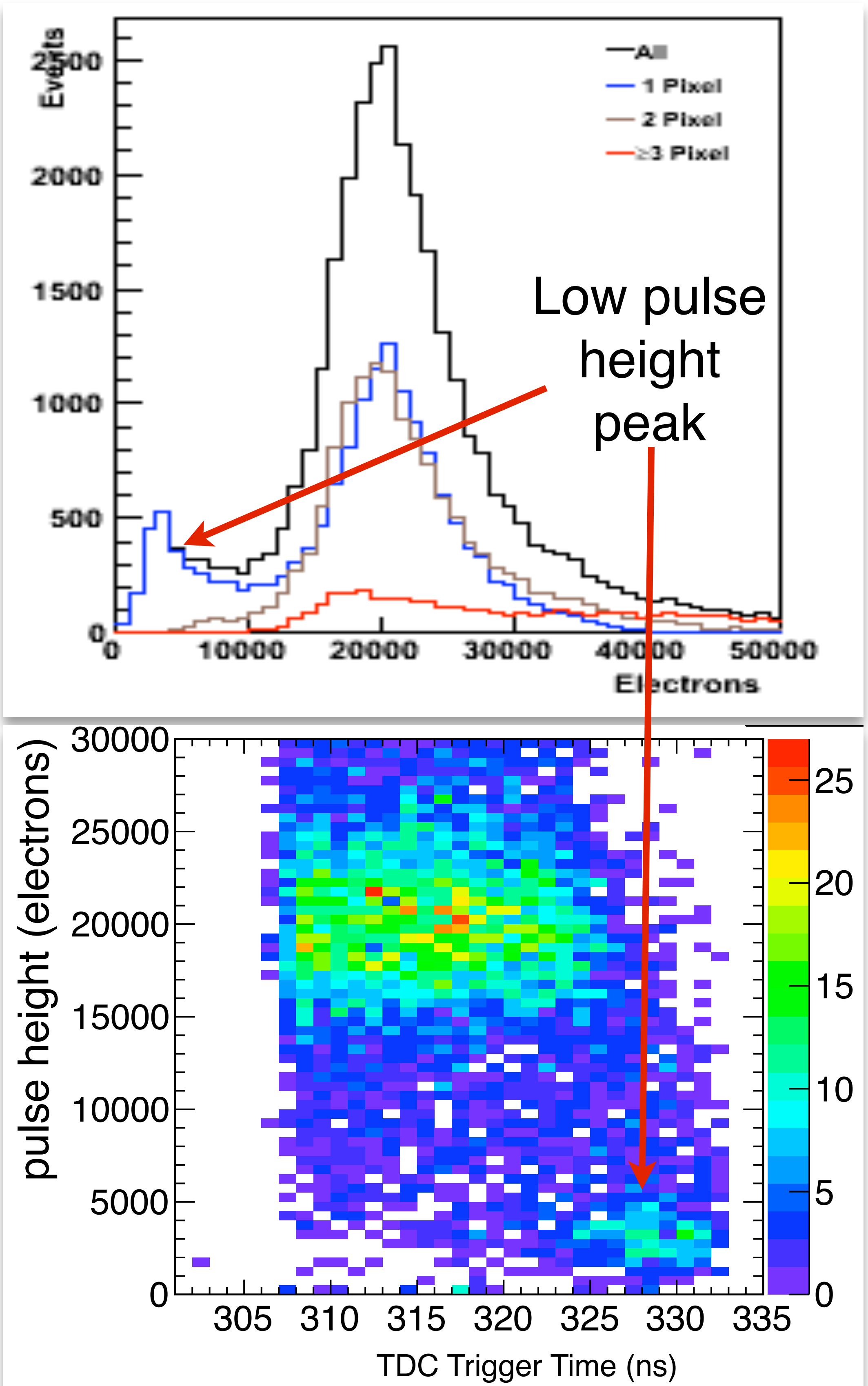
Pixel AOH

FastOr AOH

PLT: Results

- PLT has been tested in several test beams
- Measured:
  - Pulse heights,
  - tracking,
  - pixel occupancies,
  - efficiencies
- Exercised the DAQ system
- Behavior in magnetic field

PLT results: Pulse heights



- PS test beam
  - 10 GeV pions
- Most probable pulse height is around 20k electrons
  - Consistent with a MIP hypothesis in 500 μm single crystal diamond
- Average pulse height is consistent between one and two pixel clusters
- Lower peak is due to out of time triggers
  - Test beam particles arrive at random time, which is not the case at LHC

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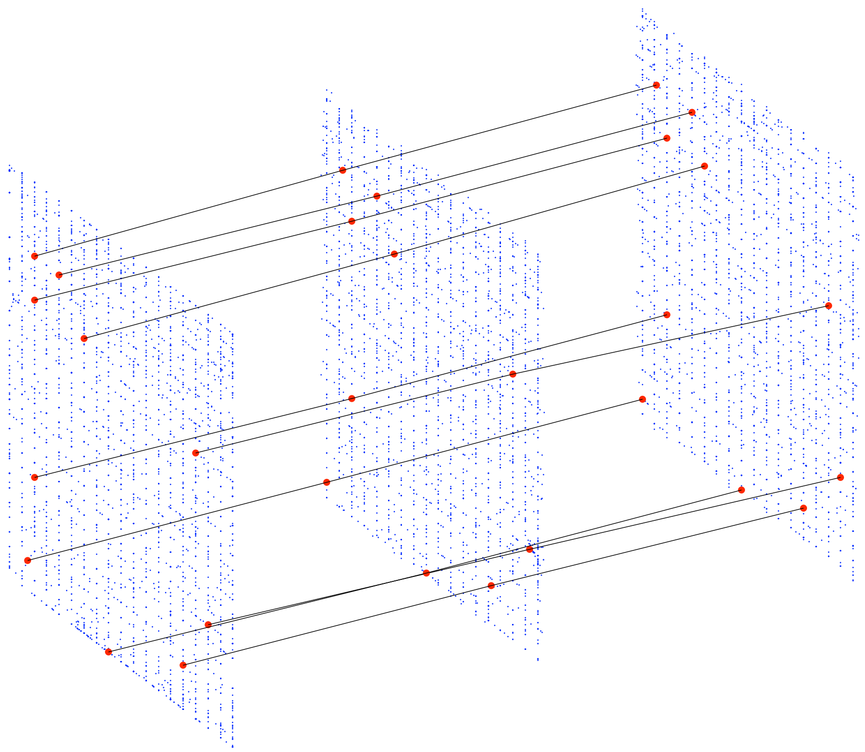
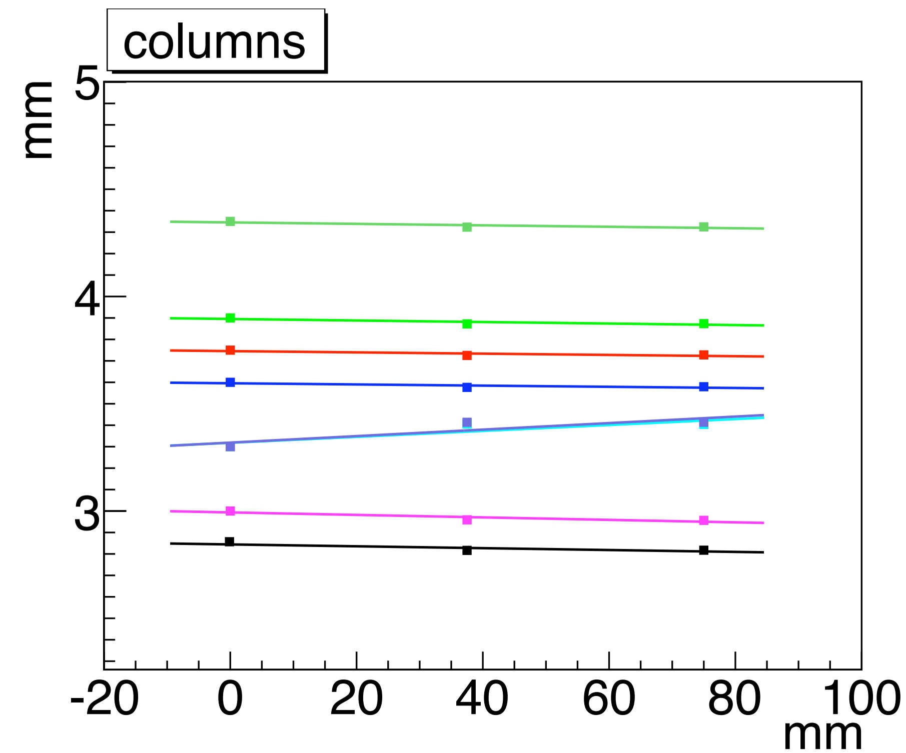
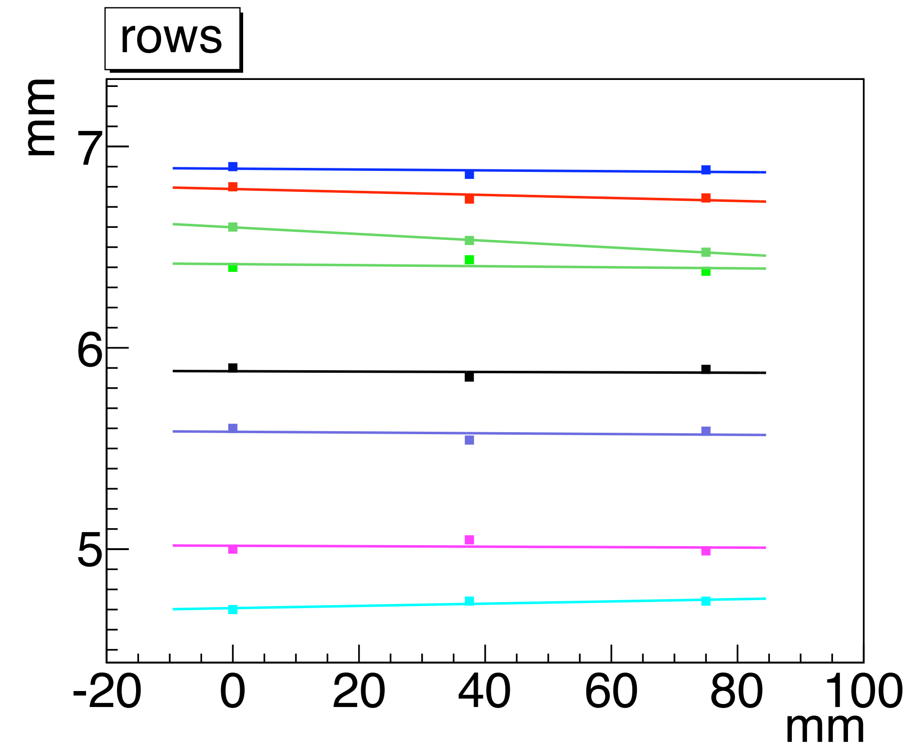
PLT Results: Tracking

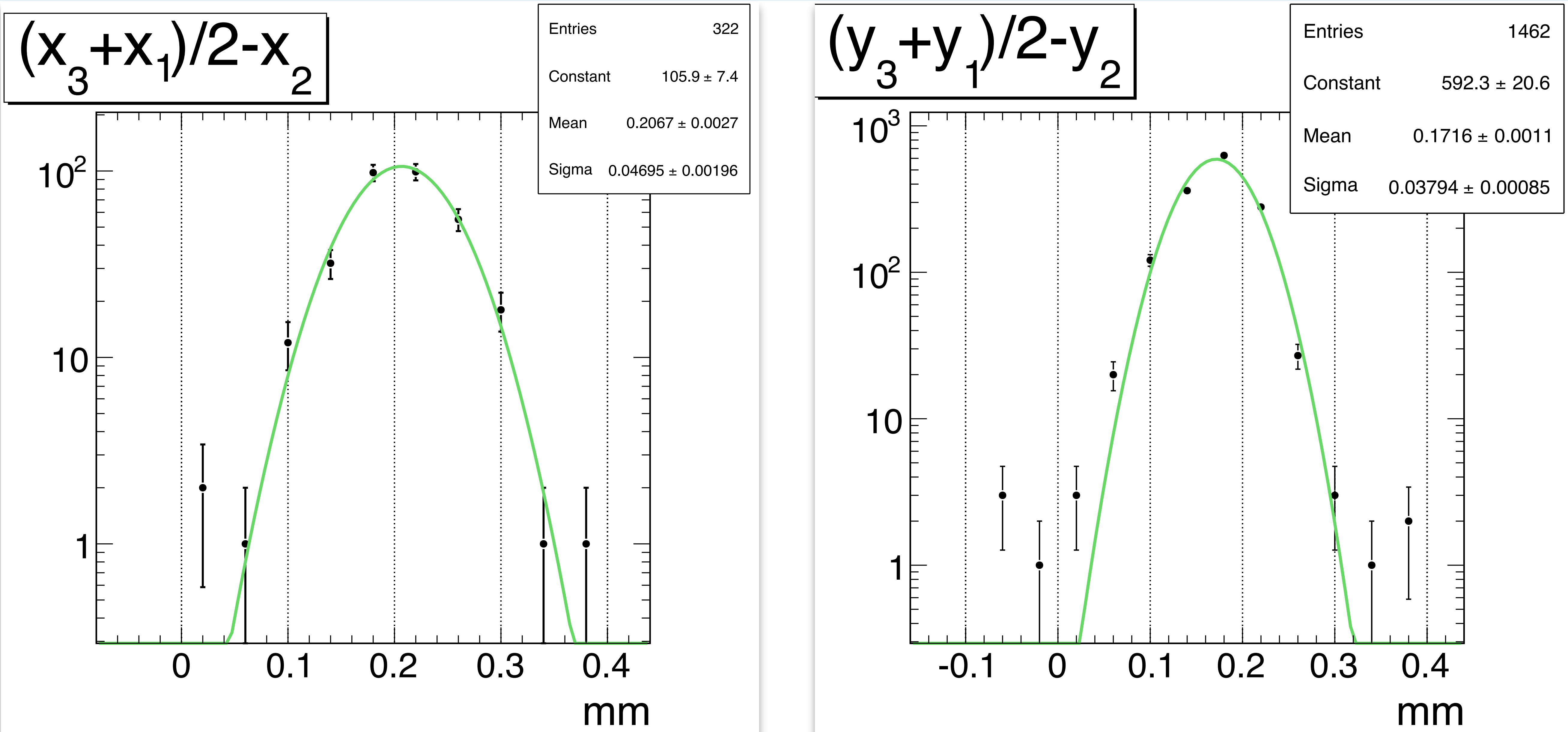
- Define cluster: group of neighboring “hit” pixels
- Define cluster position: center of gravity
- Correct for relative plane rotation
- Correct for relative plane offset
- Select events with one and only one cluster in each plane (89% of events with hits in all three planes)







PLT Results: Residuals



- Use prediction based on two planes and compare it with measured position in the remaining plane
- Only clusters with 2 pixels in the direction of the residual.
- No eta correction, just center of gravity
  - sigma < pixel pitch

Installing PLT on +Z CASTOR table

- Reasons:
  - CMS would not open during year end technical stop
- Benefits:
  - Experience installing PLT
  - Commission detector in CMS environment
  - Finalize DAQ and control software with beam
  - Record radiation levels and correlate them with sensors/electronics aging process
  - Monitor the temperature of the PLT system with Sensor fibers
  - Record tracks in forward region during 2012
    - 1st diamond tracker prototype in Fwd region
  - Precision software alignment of the telescopes
  - Measure luminosity

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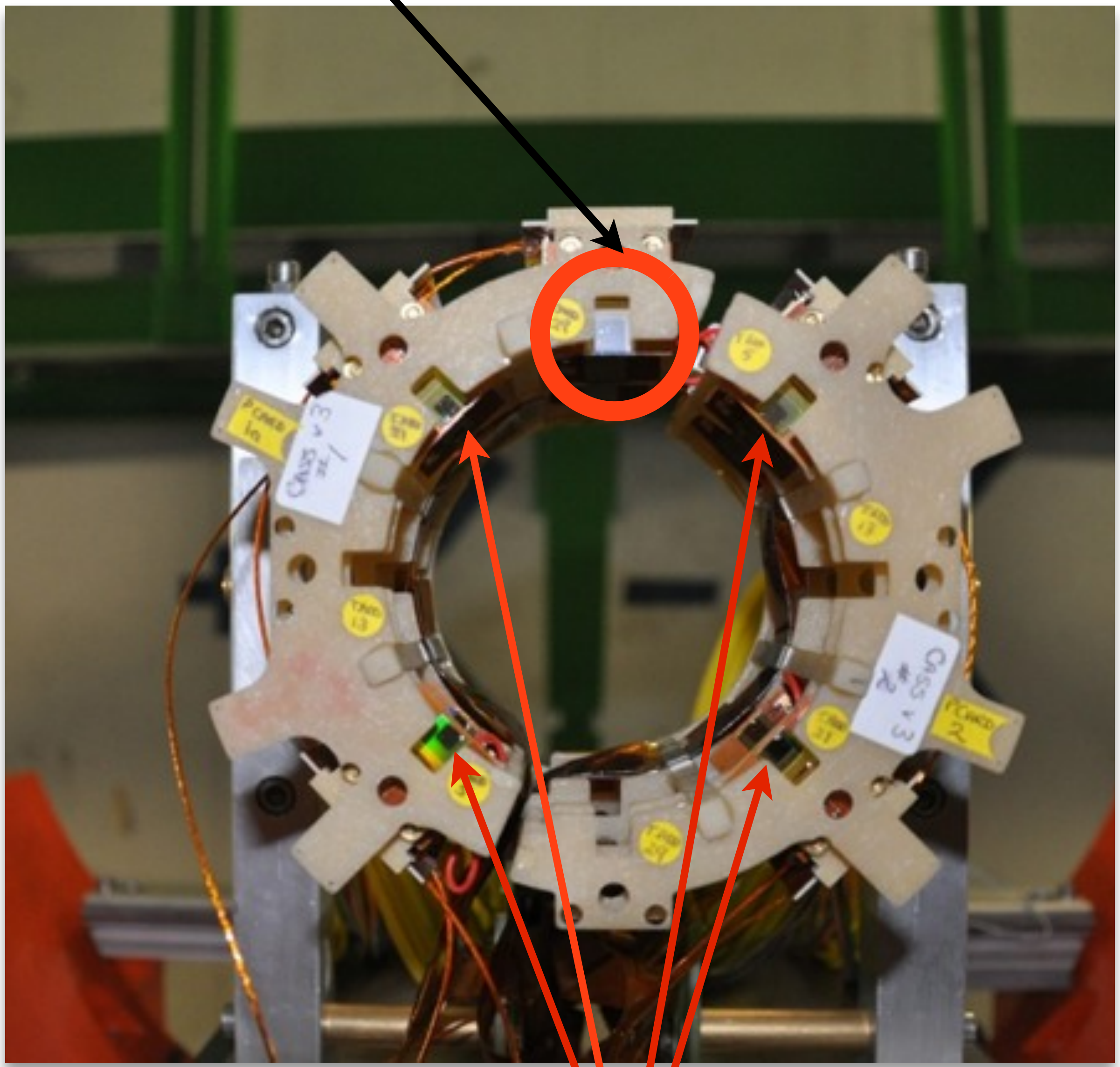
PLT on Castor table: Setup

- Only four telescopes with single crystal diamond sensors
  - Environment (radiation, temperature, humidity) is harsher in the castor area. Do not want to risk too many sensors.
- One telescope with CMS Si pixel sensors
  - Silicon telescope is put for comparison on radiation damage

Si pixel telescope



4 diamond pixel telescopes

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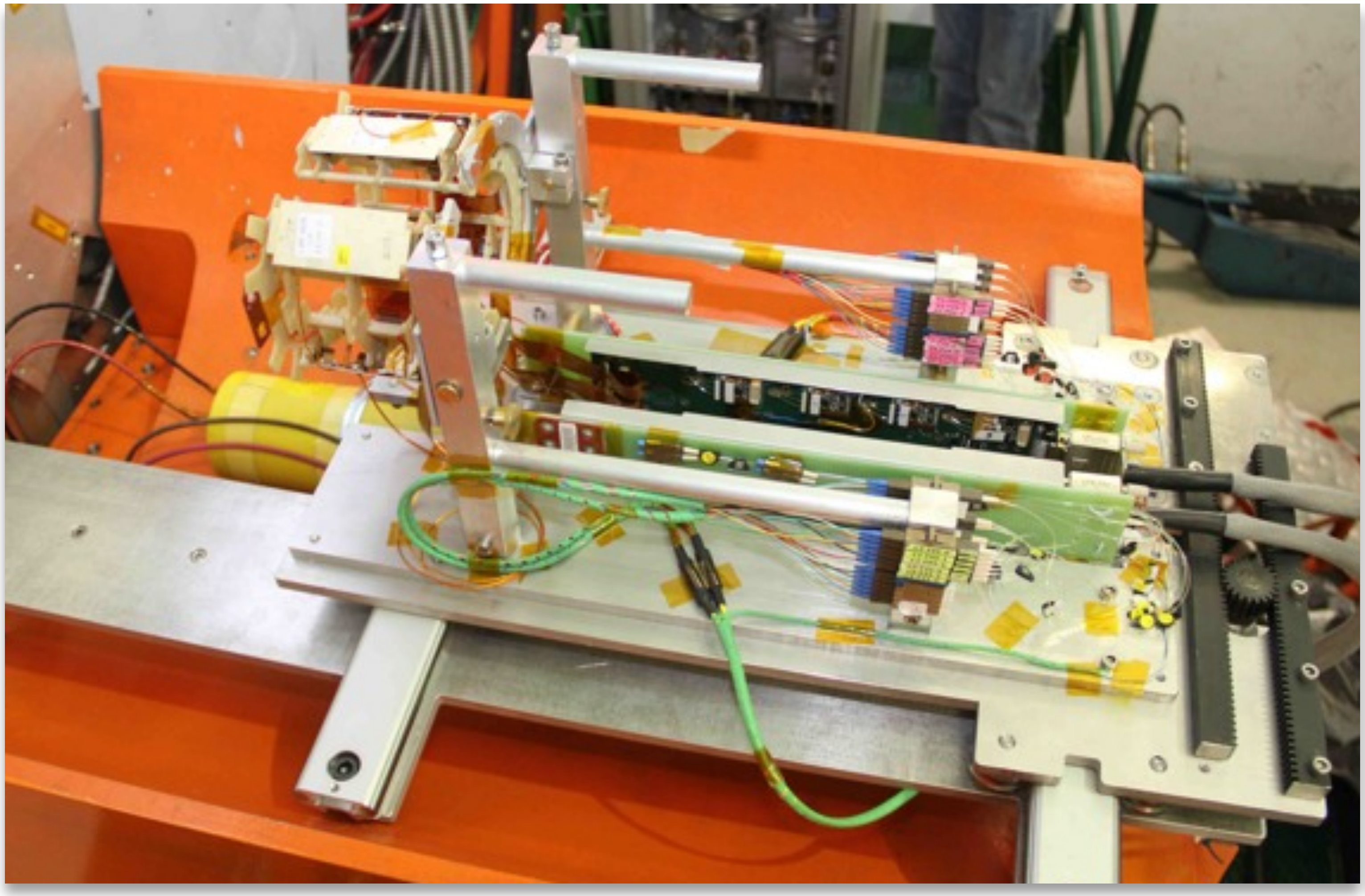
PLT on Castor table: Mechanical Support

- Aluminum support structure was designed to keep all PLT parts in the same relative position as in the final installation
  - allowed for fast PLT installation on Castor table
- PLT cassettes are separated with a gear mechanism
  - cassettes were separated before PLT was brought up to beam pipe level
  - can be controlled even when CMS is closed



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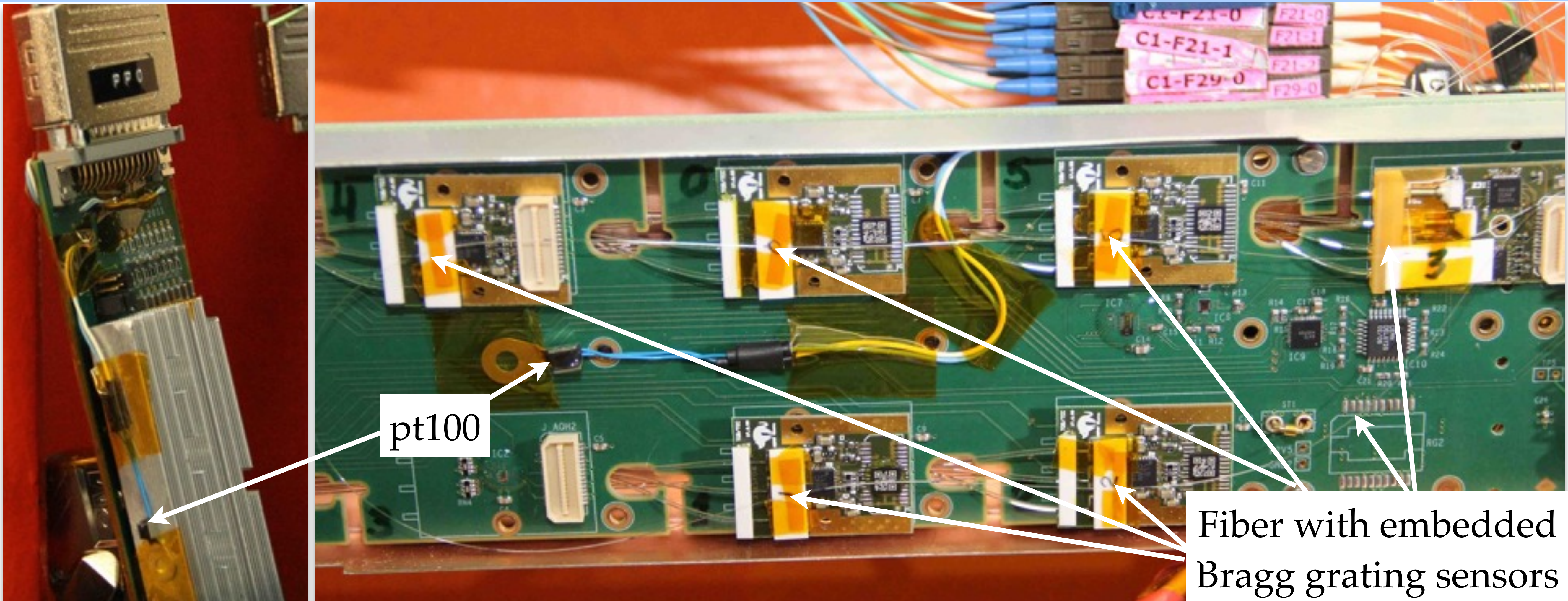
PLT on Castor table: Temperature measurement



- Measure temperature to learn its influence on detector operation
  - On each patch panel we use pt100 on top of voltage regulator heat sink
  - On each optoboard we use pt100 on top of PCB and fiber with embedded Bragg grating sensors on each AOH and DOH lasers

Summary

- CMS uses several diamond sensor based systems
  - BCM and PLT
- BCM has already had two years of successful operation in the LHC environment
  - Provides beam background monitoring, which is used as a reference of beam condition by other detectors and the LHC
  - Insures detector safety by triggering beam abort when unsafe beam conditions are detected by it
- PLT - is installed for the pilot run this year on Castor table 15 m from the IP (downstream of HF).
  - Installation went successfully
  - Looking forward to seeing the first tracks in the very forward region and determining the first luminosity with the PLT in the first LHC beam this year!

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BackUp slides

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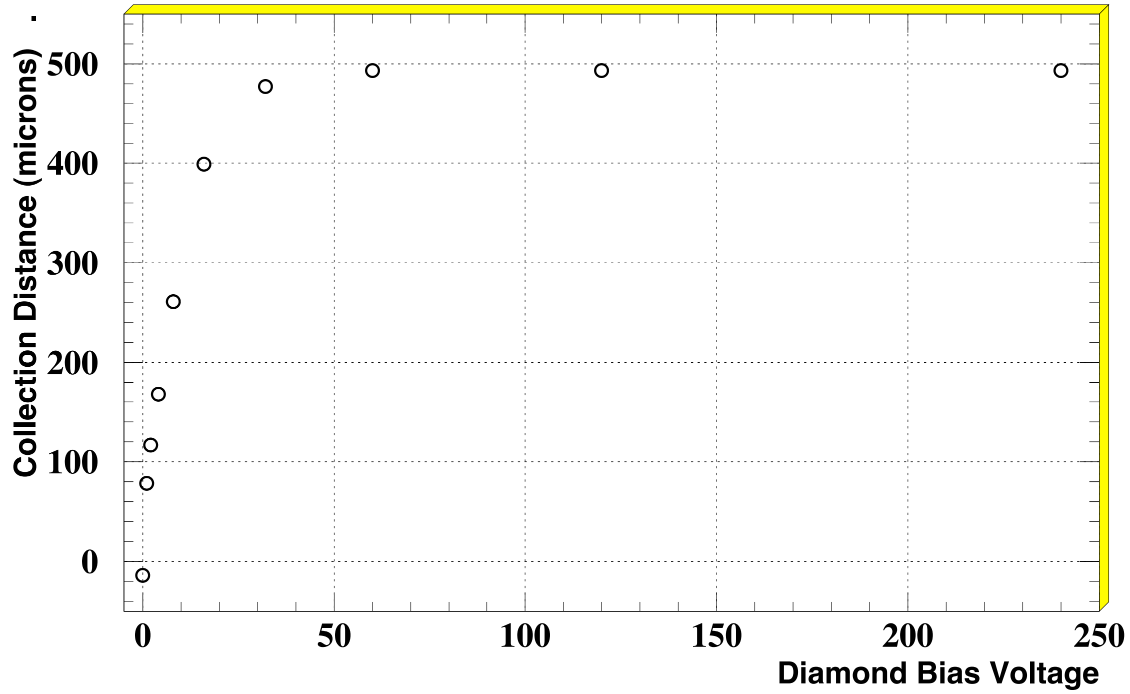
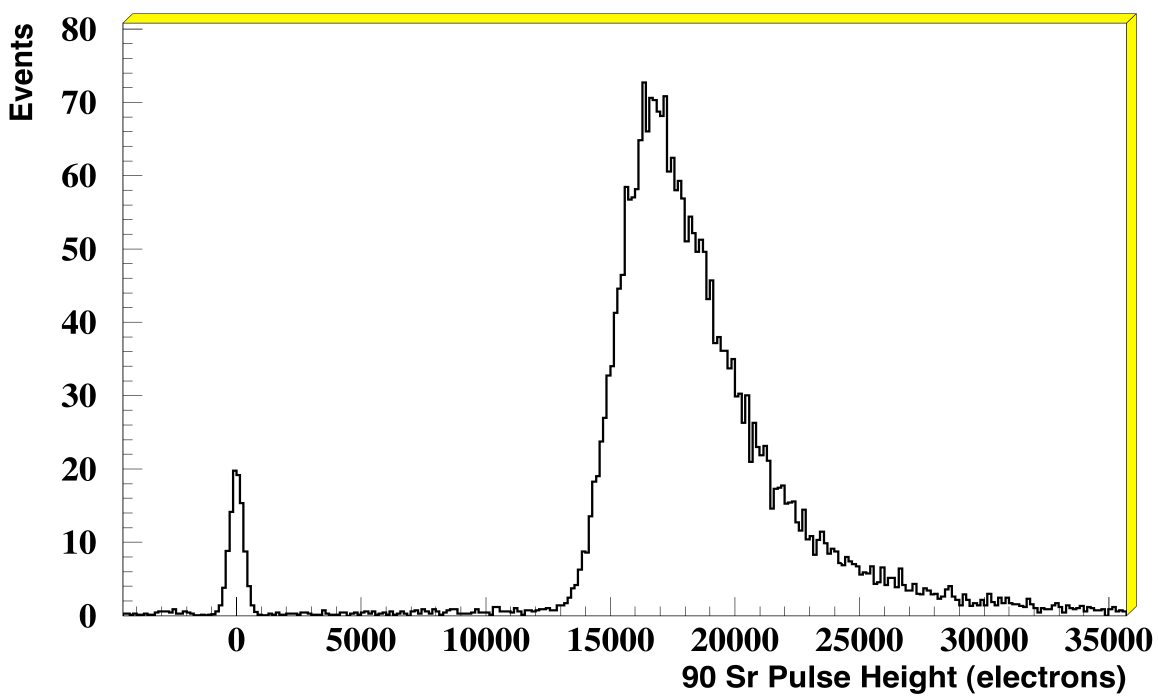
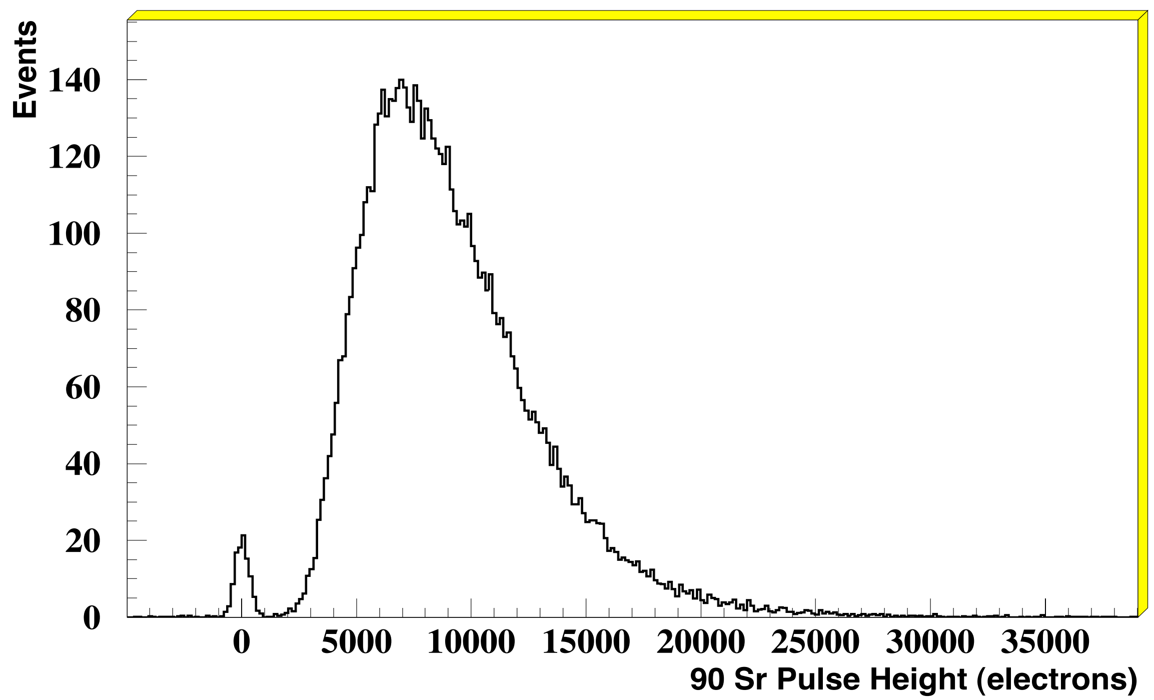
Single crystal vs polycrystalline diamonds

- Full charge collection < 0.2 V/μm
  - ➡ 18,000 e⁻ signal for 500 μm diamond
- Pulse height well separated from pedestal
  - ➡ compare poly crystalline diamond







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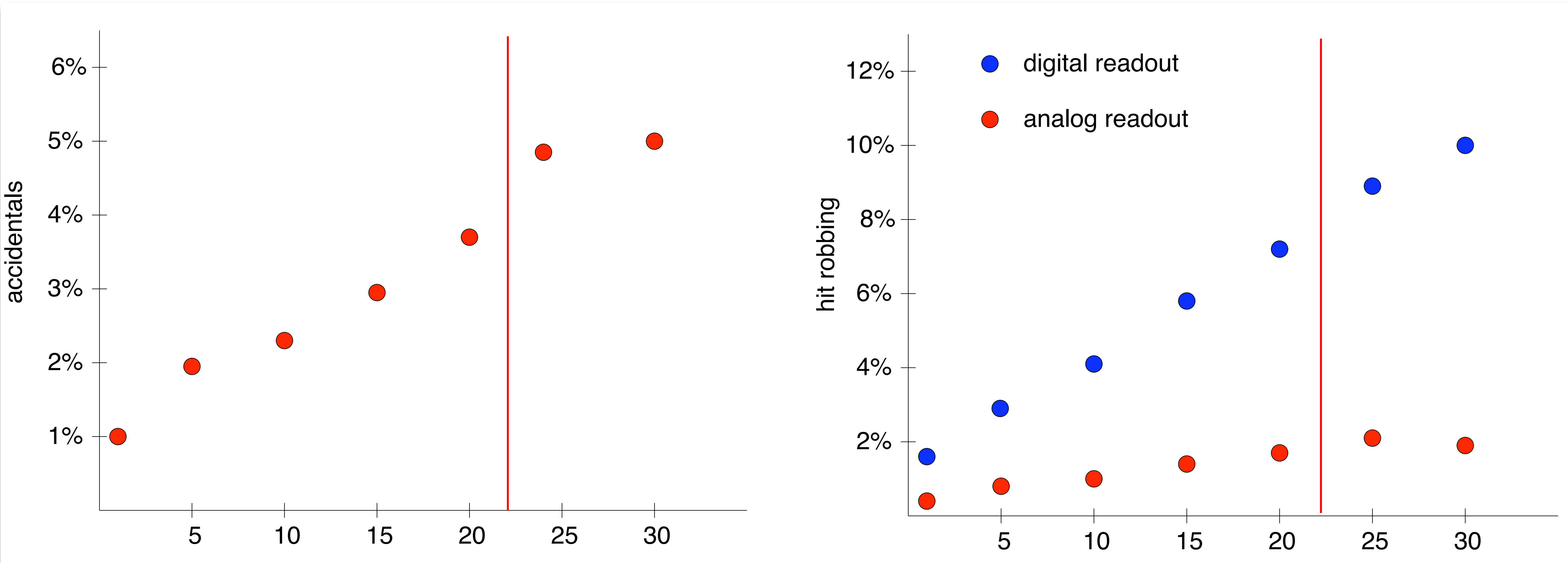
PLT design: Rates

Pythia simulation:

- 0.0048 track/pp interaction/ telescope
- For L = 10^{34} / cm^2 / s
  - 1.6 tracks in PLT / bunch crossing
- 18,000 tracks per second for each of the 2835 filled orbit bunches
  - 0.75% statistical precision in one second

PLT design: Accidentals and Overlaps



- Accidentals and overlaps are a few percent at full luminosity
- Correctable to a few percent of themselves using full pixel data

Design location of PLT

- ~ 1.7 m from IP
- Just outside of beam pipe (~ 5 cm from beam line)