THE UNIVERSITY of TENNESSEE
KNOXVILLE

BRIL

The Pixel Luminosity Telescope (PLT) of CMS

Grant Riley
for the
CMS PLT / BRIL Collaboration

Luminosity Measurement

- Luminosity is limiting source of uncertainty for limit setting and, cross section measurements (high precision measurements of Higgs)

- Luminosity measured in Run I with
  - Hadronic Forward Calorimeter (HF) and Pixel detector

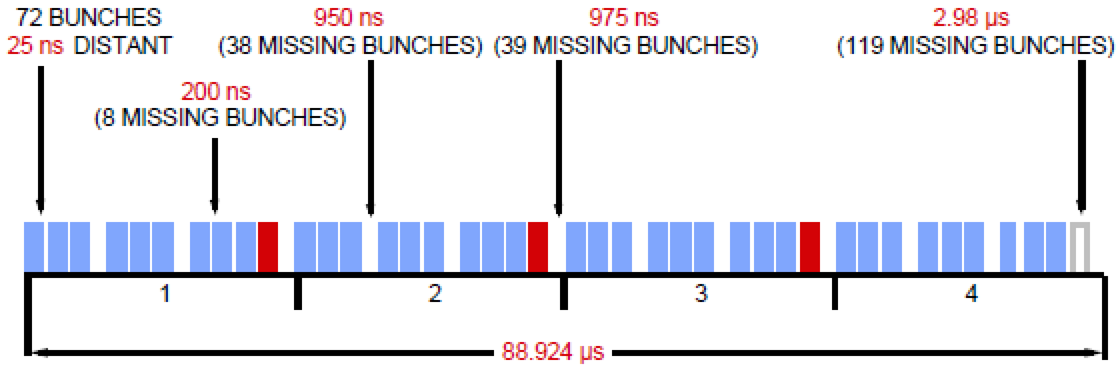
    + well known cross section measurements (W, Z production)

    ➔ relative precision: ~ 2.5%

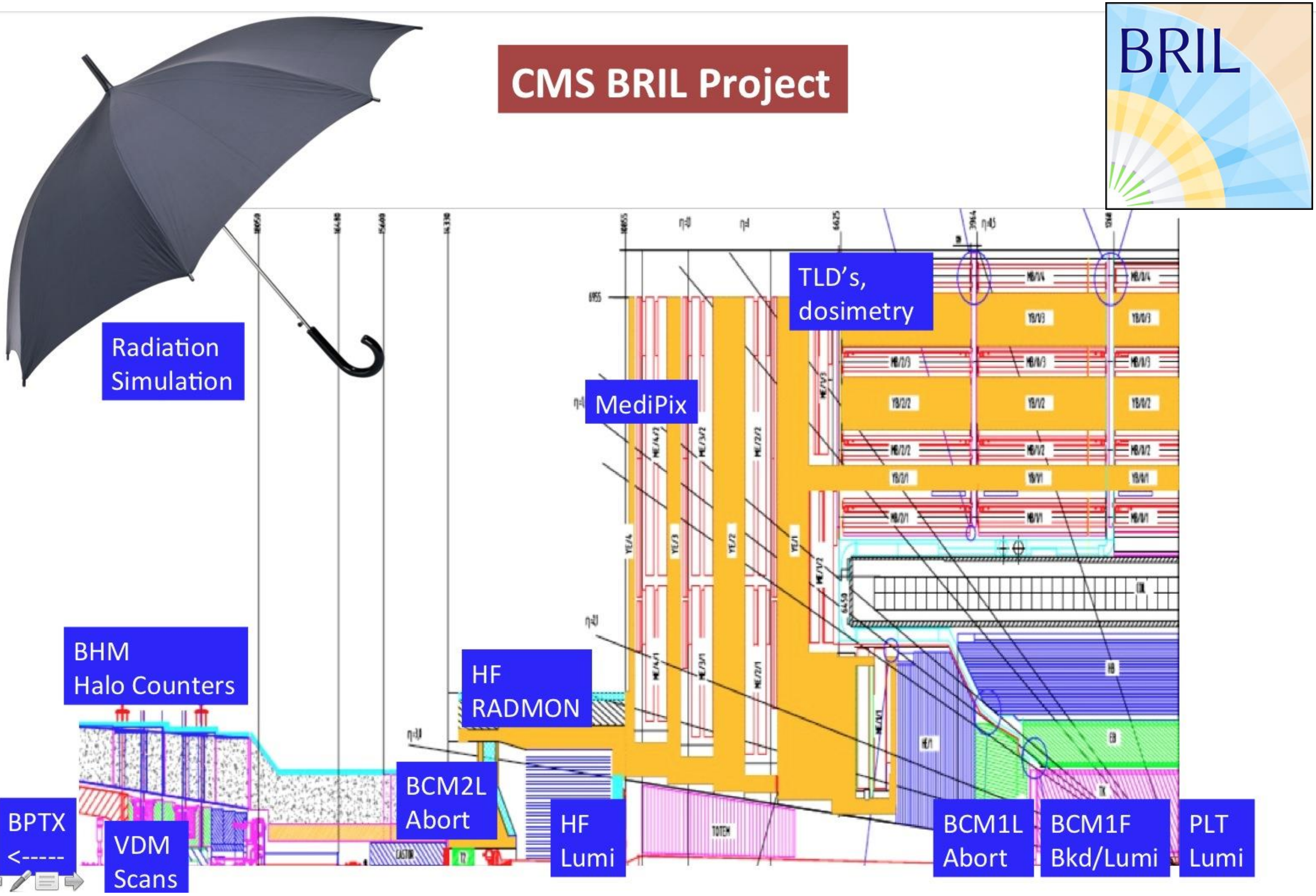
- PLT is a dedicated luminosity monitor for Run II
  - Standalone system of CMS (self triggering, independent data taking)
  - Bunch-by-bunch luminosity (1% statistical precision In 1second at full luminosity)

  - Beam background
  - Collision point centroid

→ LHC fill pattern



Beam Radiation Instrumentation and Luminosity - Overview

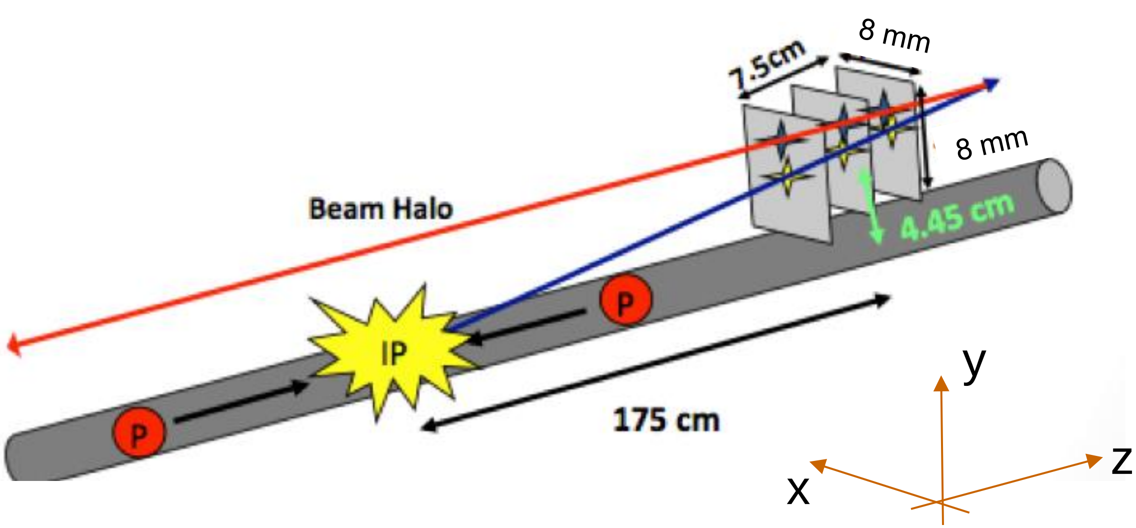


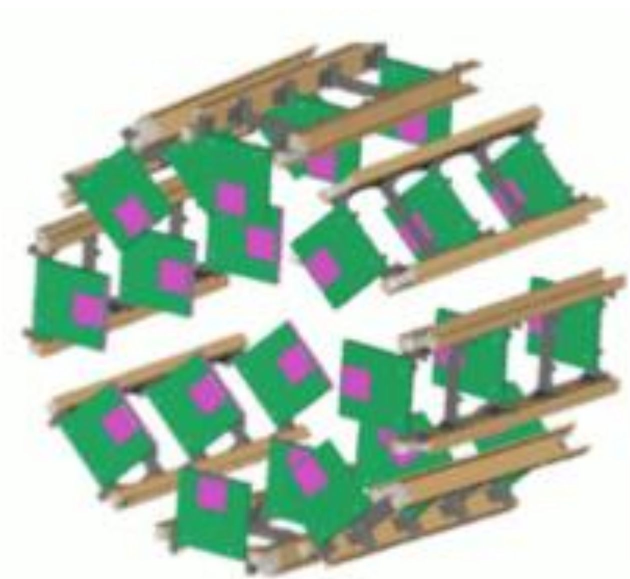
The PLT Collaboration

- CERN
- Karlsruhe Institute of Technology
- PSI
- Princeton University
- Rutgers University
- University of Tennessee
- University of Wisconsin
- Vanderbilt University
- Vienna Institute for High Energy Physics

Pixel Luminosity Telescope

- 8 telescopes per CMS side (+/-Z) with three silicon detector planes each measure triple coincidence rates and particle tracks
- Same pixel readout as the CMS pixel detector + fast trigger
- Detector acceptance well defined (survey of position, alignment); can be varied by masking pixels
- From simulation for 14 TeV runs with 21 interactions / bunch expect ~5 coincidences in PLT / bunch crossing





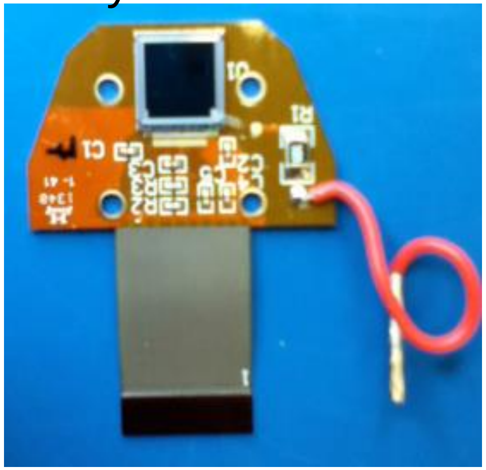
System Components

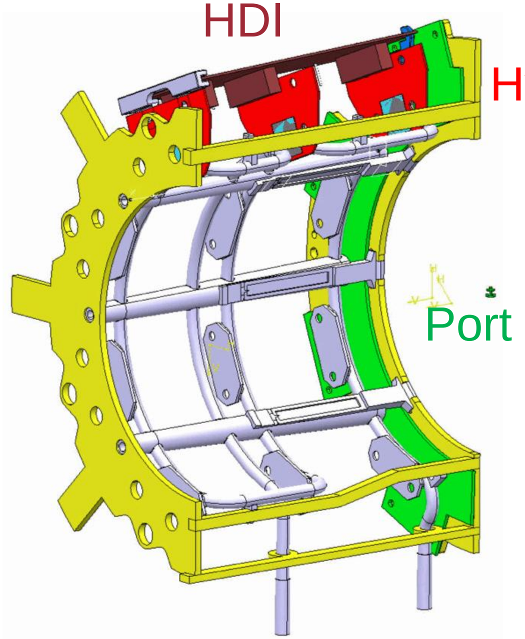
- Readout chain
  - Hybrid board
  - HDI
  - Port Card
  - Opto-Motherboard
  - Front End Driver (FED)
  - PC

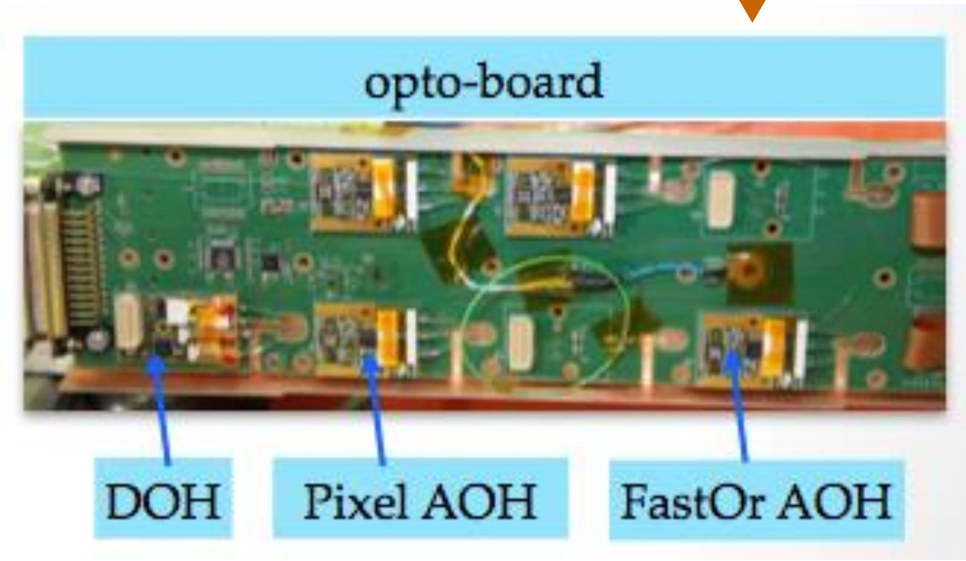
Inside CMS volume (Hybrid board, HDI, Port Card, Opto-Motherboard)

Service cavern (Front End Driver (FED), PC)

PLT Hybrid board → Port Card

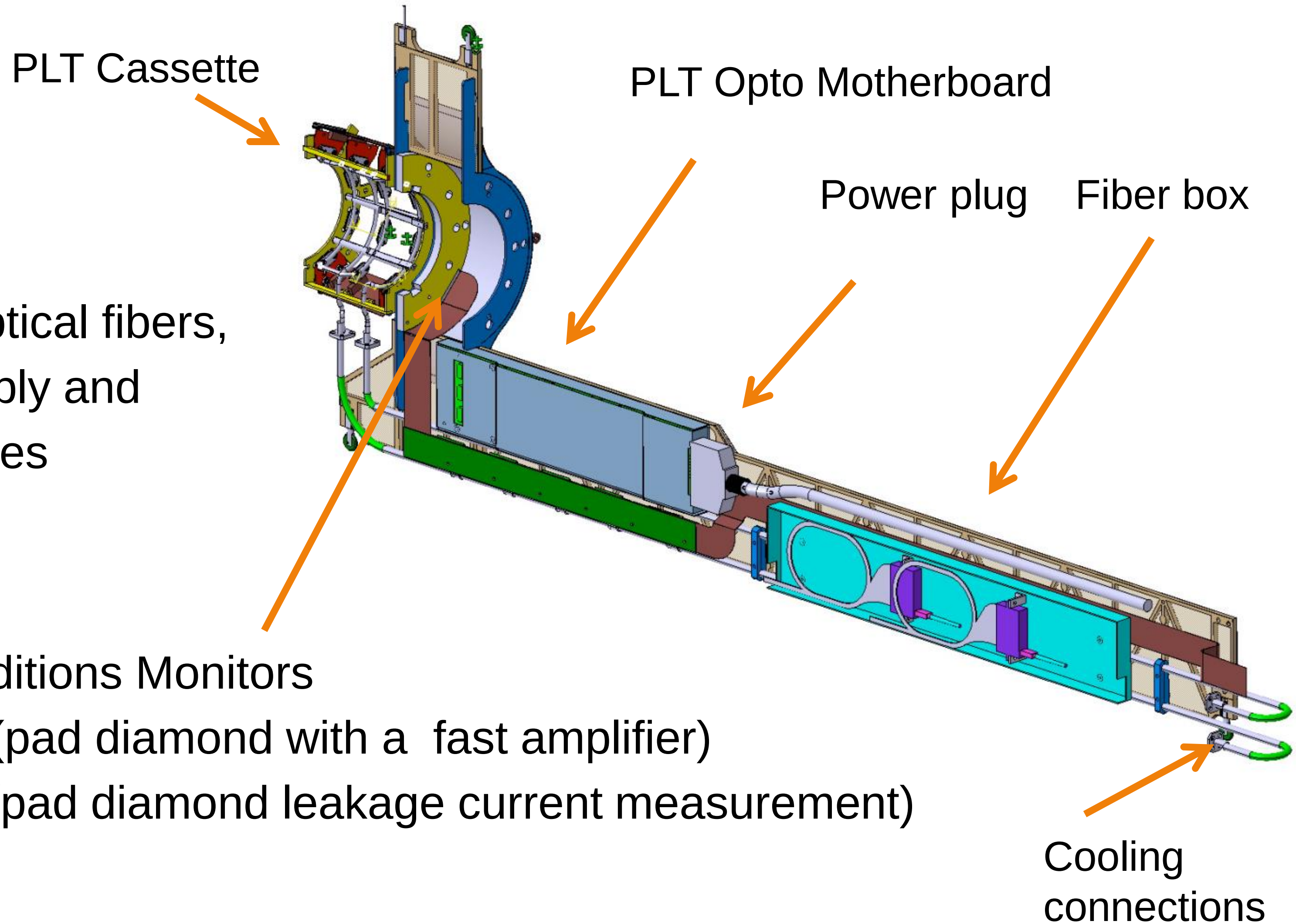






Pixel Luminosity Telescope

- PLT shown mounted on carriage



- Includes optical fibers, power supply and cooling pipes

- Beam Conditions Monitors
  - BCM1F (pad diamond with a fast amplifier)
  - BCM1L (pad diamond leakage current measurement)

Silicon Detector

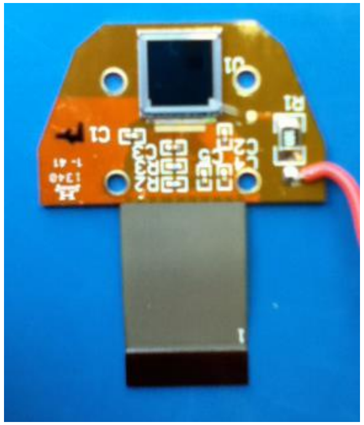
- Silicon comes with some limitations
  - Temperature dependence of charge signal (calibration)
  - Radiation damage – type conversion; noise level

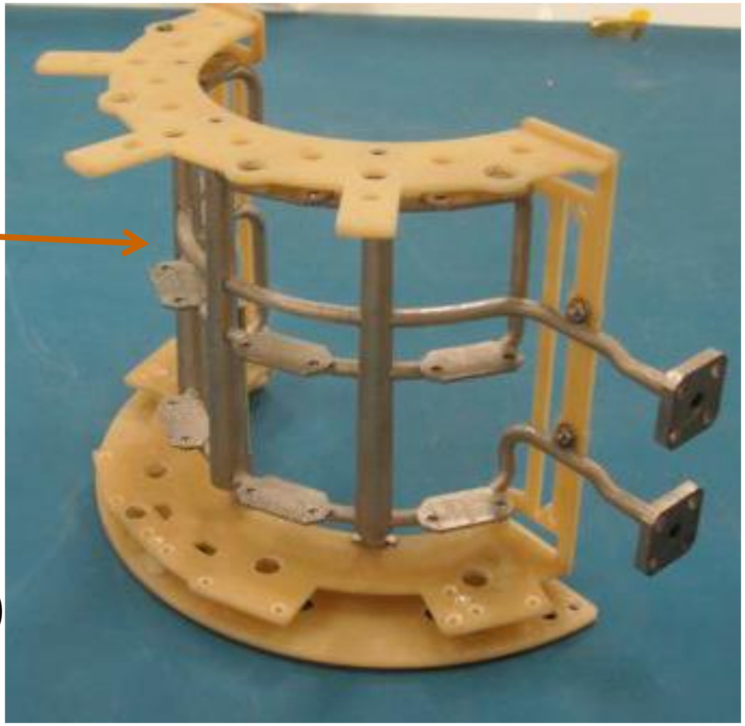
  i.e. temperature needs to be low and stable

  ➔ Add cooling infrastructure

  ➔ Add temperature monitoring
- Titanium-alloy cooling structure "3-D printed" to specs
  - selective Laser Melting
  - rated to >15 Bar of coolant pressure
- Hybrid board reshaped & thinned to better cool the sensor
- Silicon bump bonding at PSI (standard CMS pixel detector assembly)

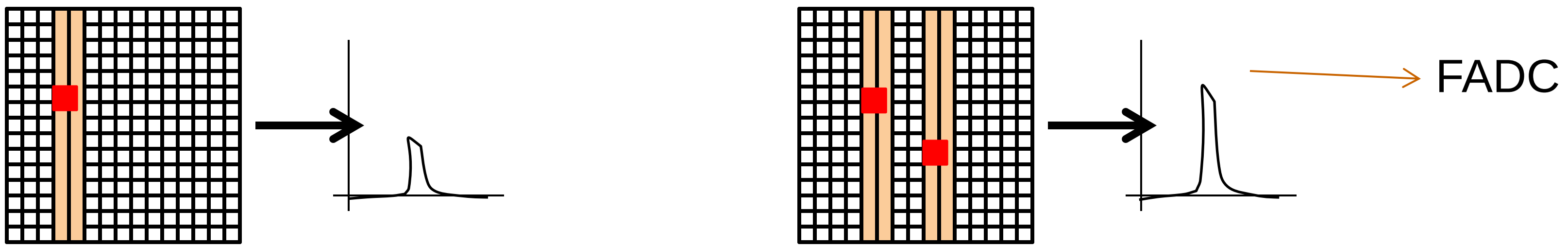
PLT Hybrid board





Readout Modes

- PSI42 pixel chip has 2 read-out modes
  - Fast-out feature
    - Fast signal from hit in pixel double column
    - 3-fold fast-out coincidences at each bunch crossing (40MHz)
    - Signal height is based on number of well separated hits

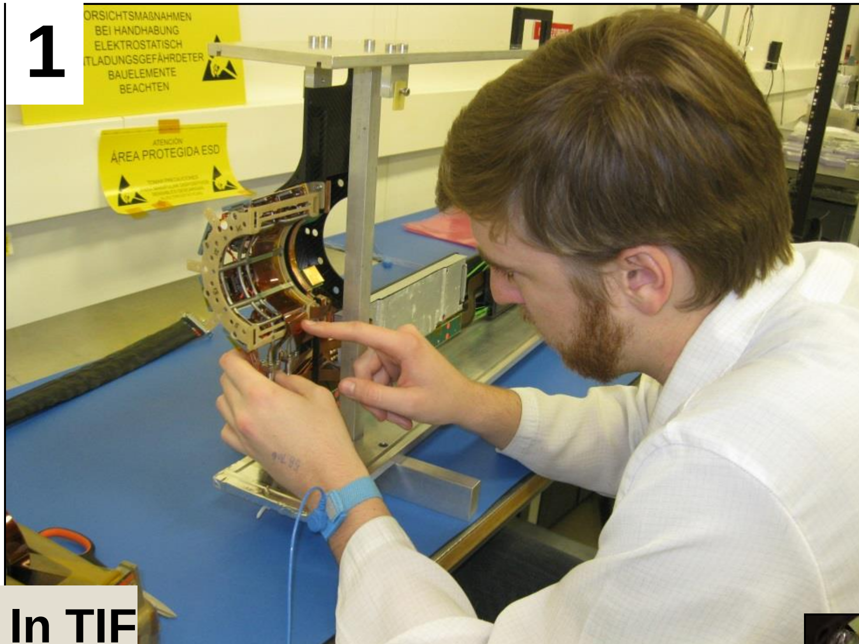


  - Full pixel readout
    - Address and charge deposit of each pixel hit
    - Can be read out ~1 to 10 kHz
    - Can be triggered by fast-out (self trigger) or by external trigger (beam clock, random ..)

→ Diagnostics: Pixel efficiencies, correction for accidentals, overlaps

→ collision point centroid, beam halo

PLT Installation @ P5

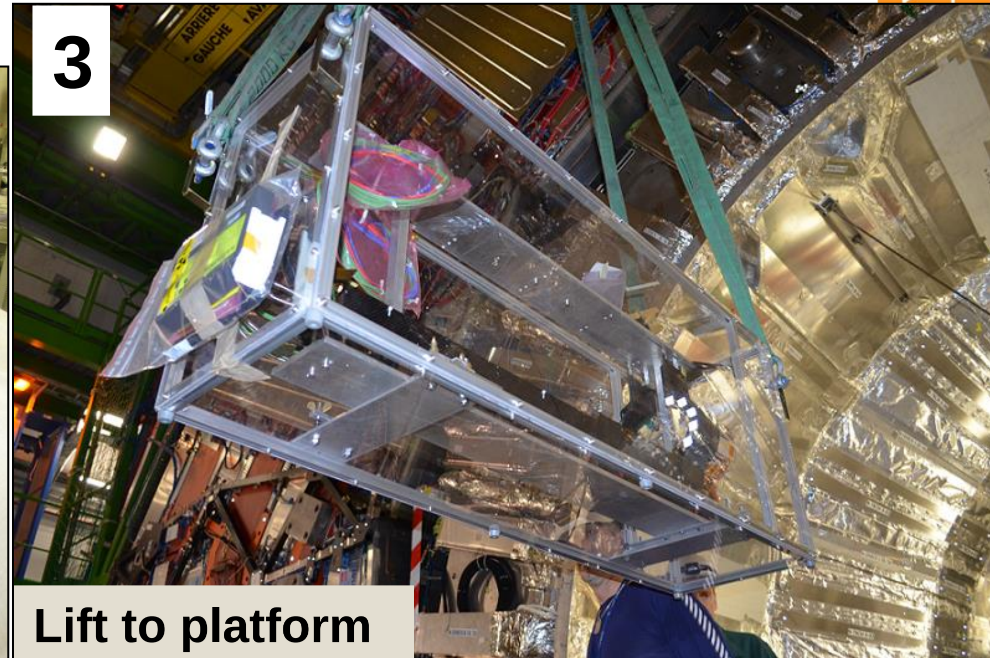


1

In TIF

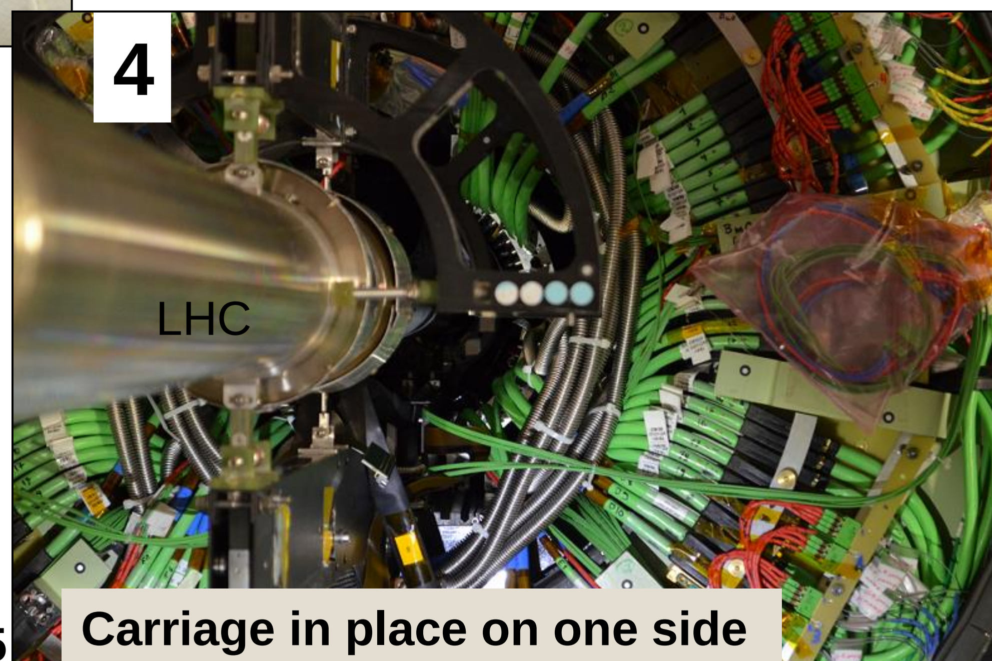
2

Transport to P5



3

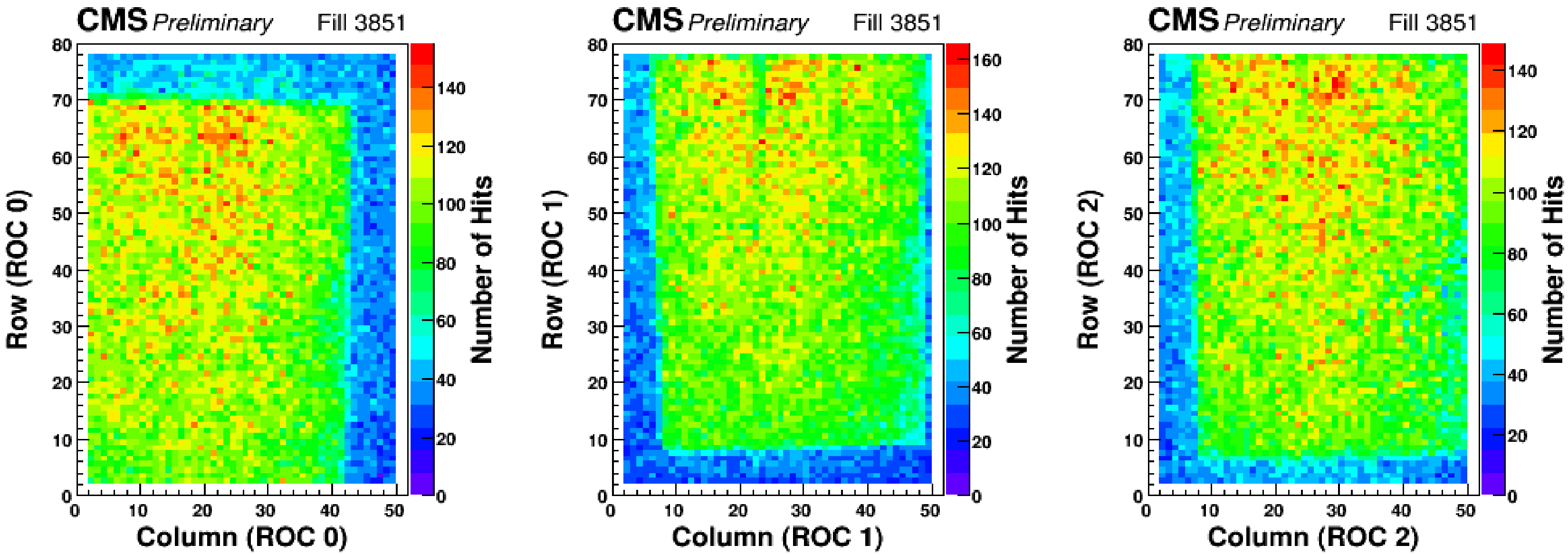
Lift to platform



4

Carriage in place on one side

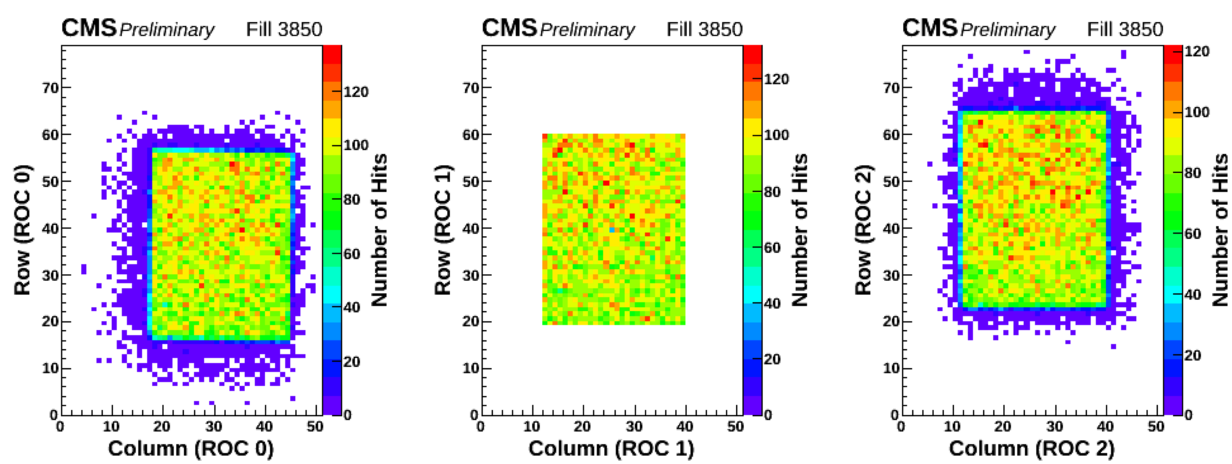
Hit Occupancy



Hits in 3 planes of a telescope from a single 13TeV LHC Fill. Triggered by triple coincidence anywhere in PLT

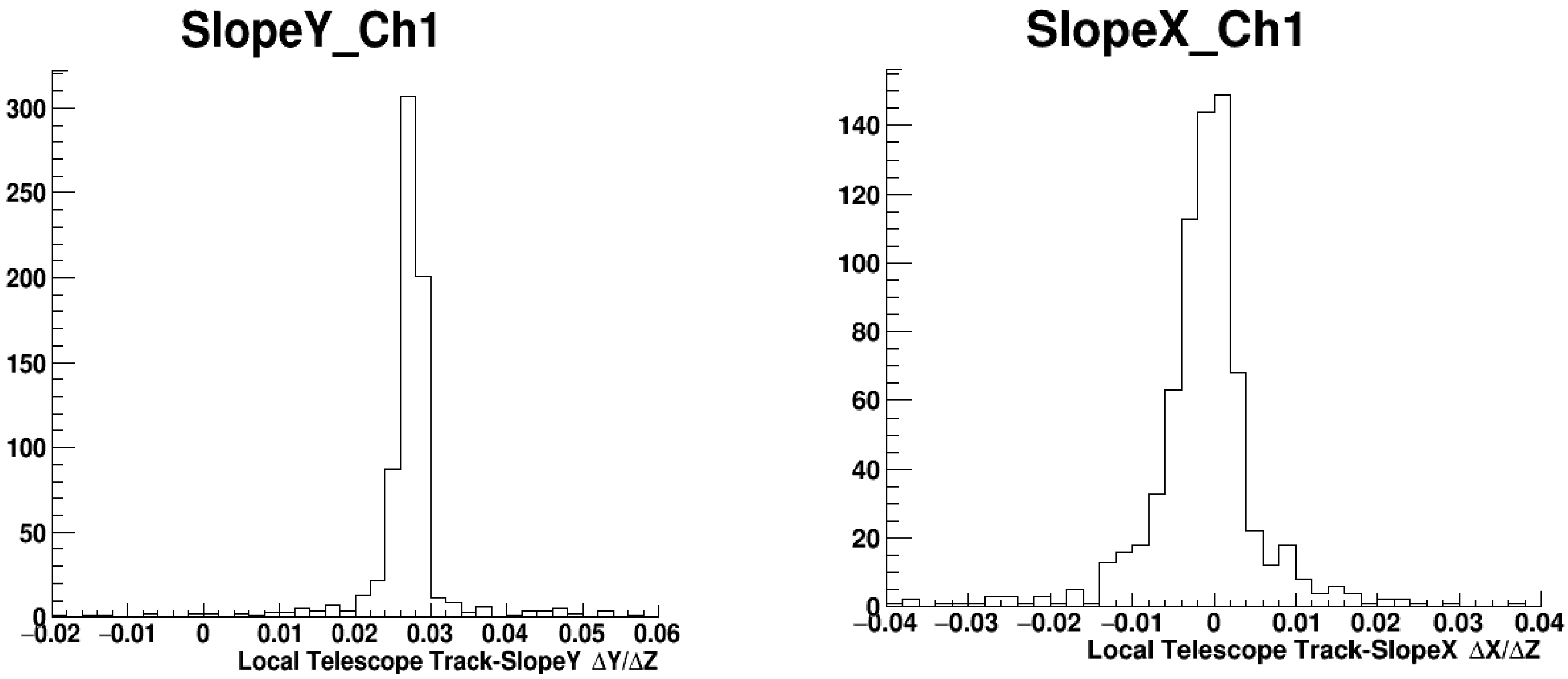
→ alignment, efficiency (uniformity), acceptance region

Events with triple coincidence in this telescope
Middle detector masked to a 4x4 mm^2 central area.



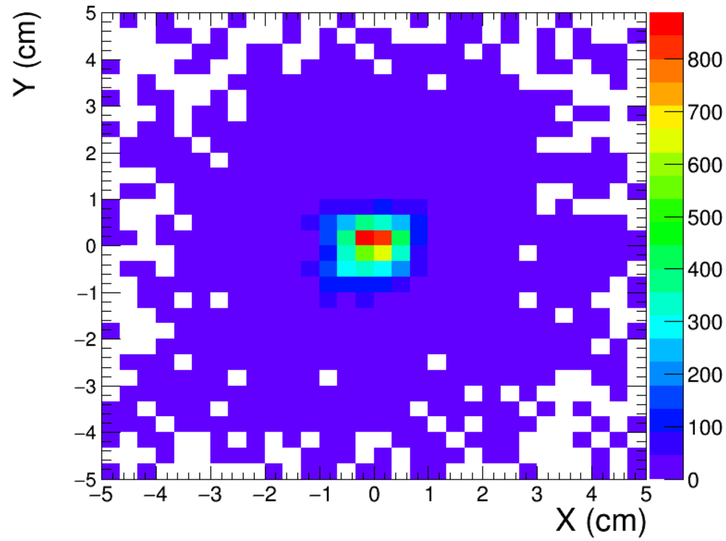
Tracking

- Use pixel hit information to measure the acceptance of the PLT
- Fit 3 single-pixel hits to straight tracks in x and y ($a_{x,y} + b_{x,y}z$)
- Shown here are the slope ($b_{x,y}$) distributions for a sample of tracks in a telescope
- X slope centered at 0, Y slope centered at slope of PLT (0.027)

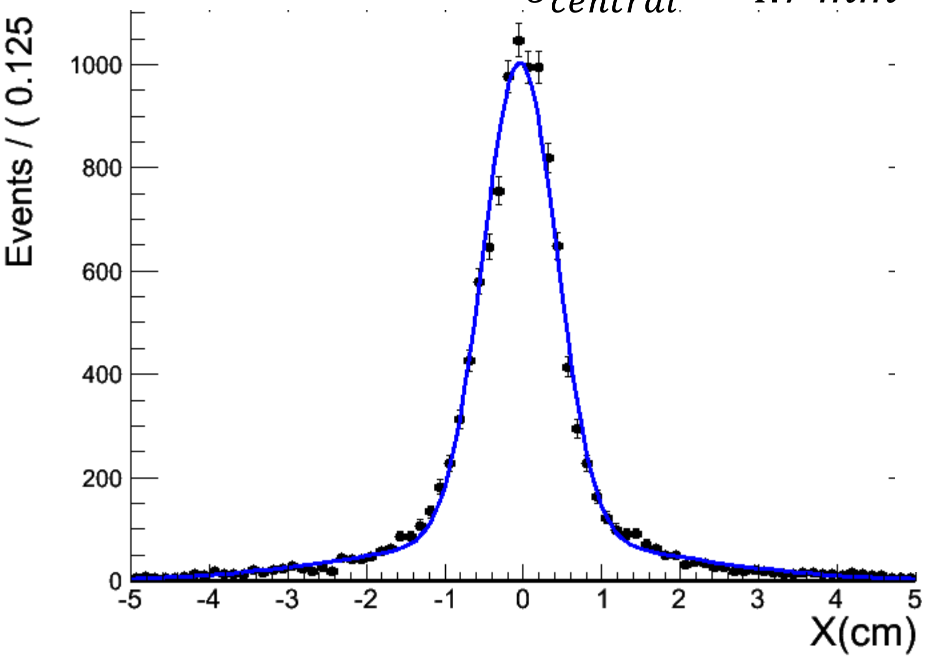


Beam Spot Centroid

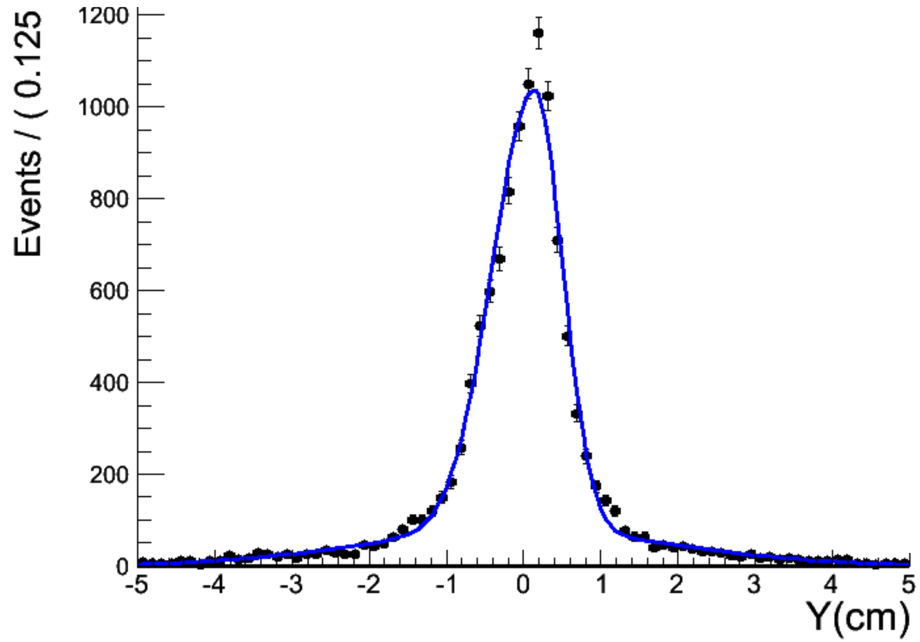
- From a 13TeV run taken on July 12
- Extrapolate tracks to Z=0 ($a_{x,y}$)
- Fit beam spot projections with double Gaussian
- Can monitor centroid online ~0.1 Hz



$\sigma_{central} = 4.7\ mm$

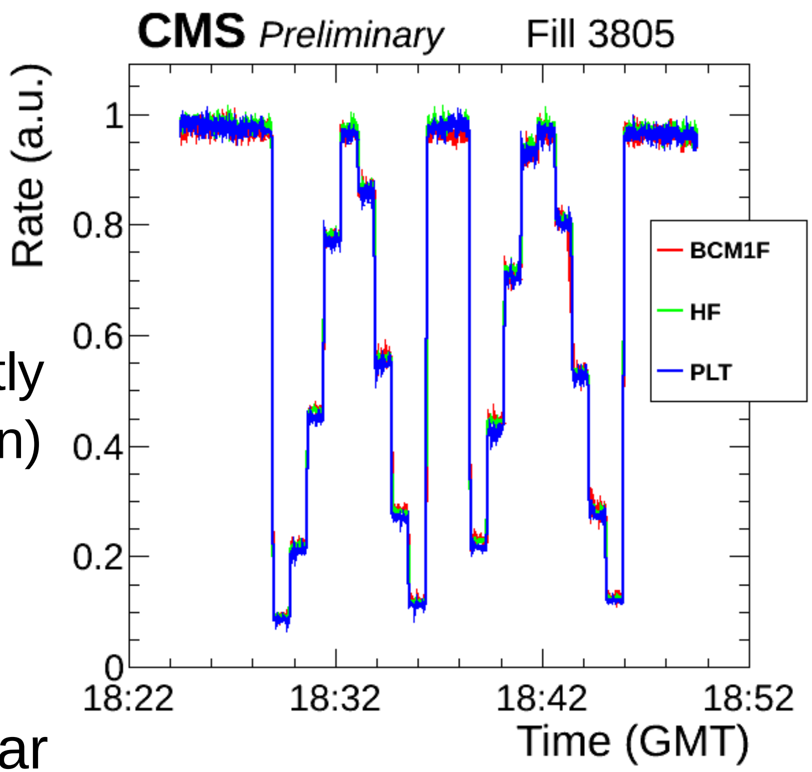


$\sigma_{central} = 4.5\ mm$



Beam Separation Scans

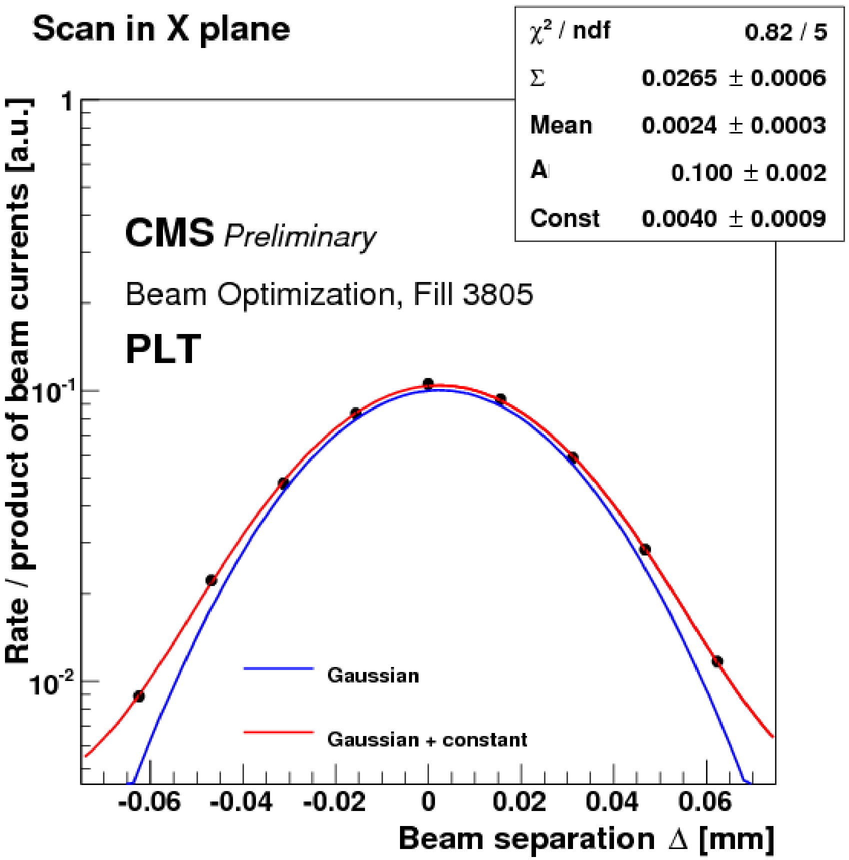
- LHC's frequent beam optimization scans
  - Right plot shows PLT with 2 other detectors (HF, BCM1F) measuring luminosity over an order of magnitude change
  - Detectors were calibrated independently (normalized to 1 separately before scan) → consistent measurements

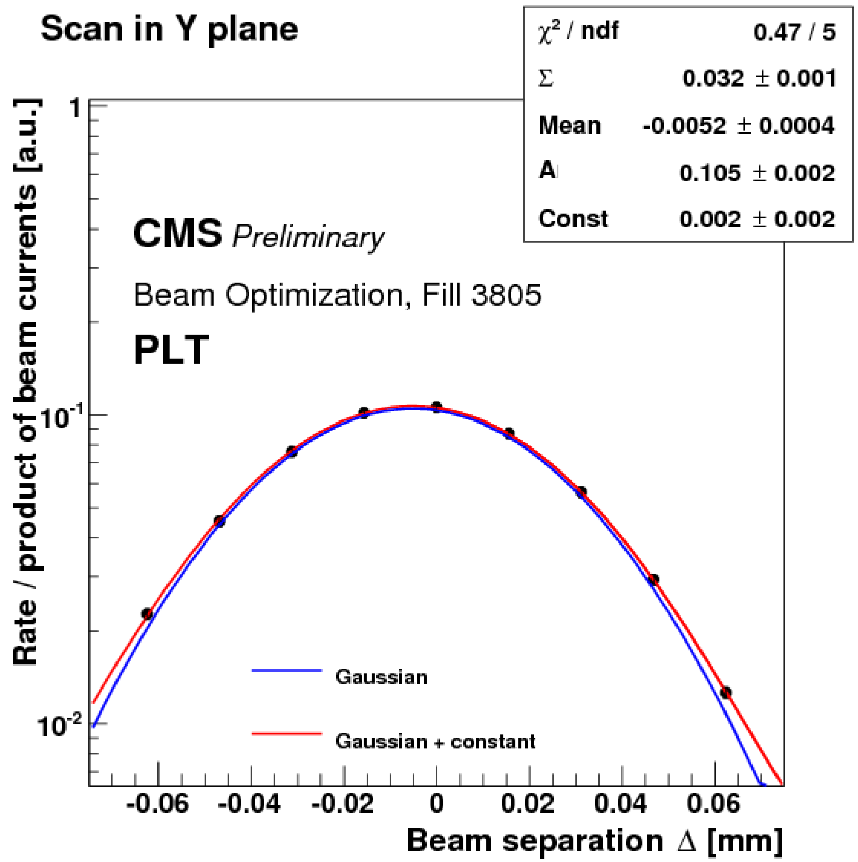


- Optimization scan almost every fill
- Full van der Meer scan ~twice per year
  - Scheduled for late August
  - Done with ~20 well separated bunches
  - Will provide more scan points and more statistics (time) per point
  - Allow for low systematic error on final luminosity calibration

van der Meer Analysis

- Plot scan points (Beam separation vs. Rate/beam current) for optimization scan (eventually for full vdM scan)
- Fit with Gaussian + constant to extract sigma (Σ) and peak value of rate/current ($A_{x,y}$) to be used in luminosity calibration





Absolute Luminosity Calibration

- Use visible cross section, σ_{vis} to translate measured rate into absolute luminosity

$$Luminosity = \frac{Rate_{PLT}}{\sigma_{vis}}$$

- To calculate visible cross section
- Gaussian Σ_x Σ_y yield an effective area of:

$$2\pi\Sigma_x\Sigma_y = Area_{eff}$$

- Peak Rate / Beam currents (currents given by LHC)) A_x A_y

$$\sigma_{vis} = \frac{A_x + A_y}{2} * Area_{eff}$$

- Calculate luminosity per colliding bunch, correct for slight decrease in beam current over the course of the scan

[https://twiki.cern.ch/twiki/pub/CMS/VdMLumiFramework/seminar_Rice_Sep2013.pdf]

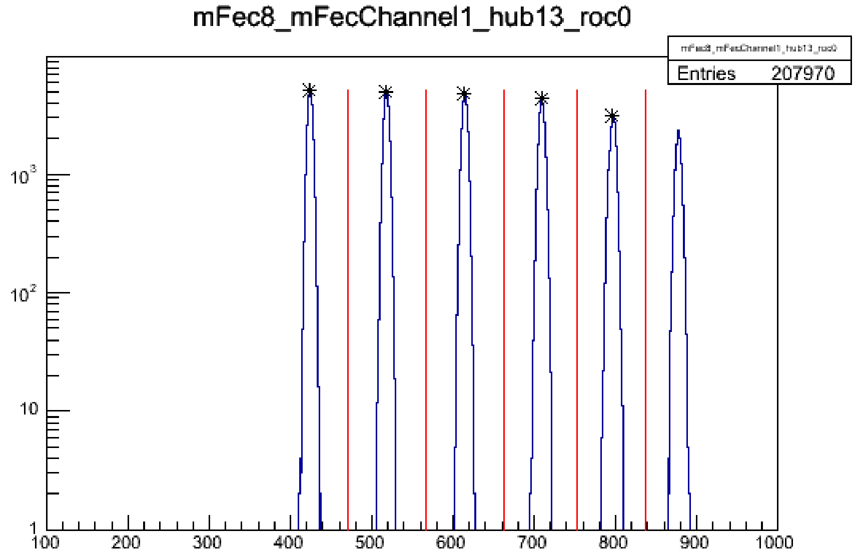
Operations and closing remarks

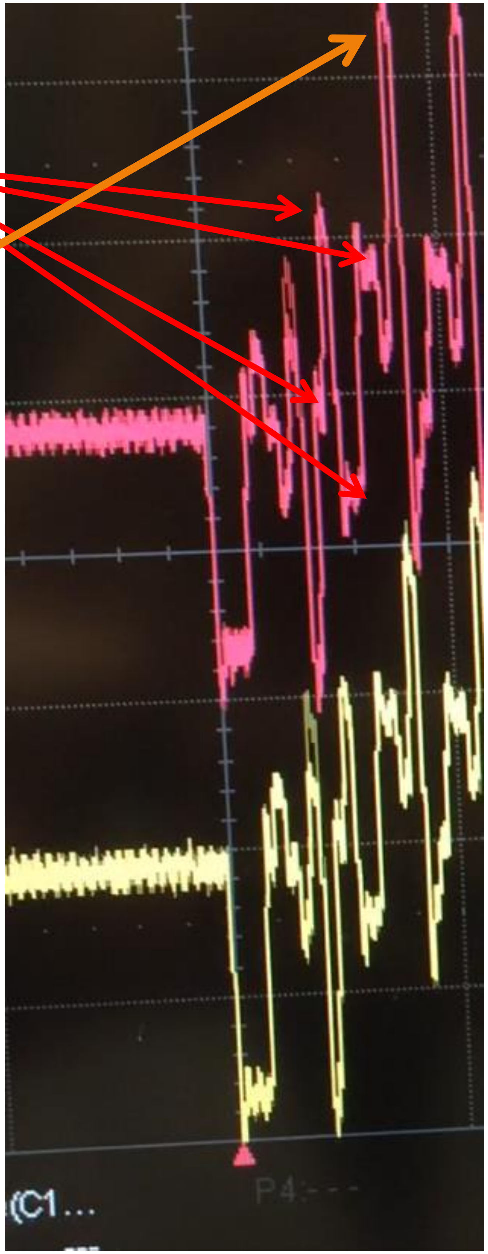
- Primary luminosity detector for recent physics collisions
- Stable, consistent : published on central CMS status page (VISTAR)
- Operational during all beam conditions
- Feedback to LHC central control room
- Working towards full automation
- Pixel data analysis is ongoing to refine Luminosity measurement even further
- Expect to improve luminosity precision for Run II

Backup Slides

Levels calibration

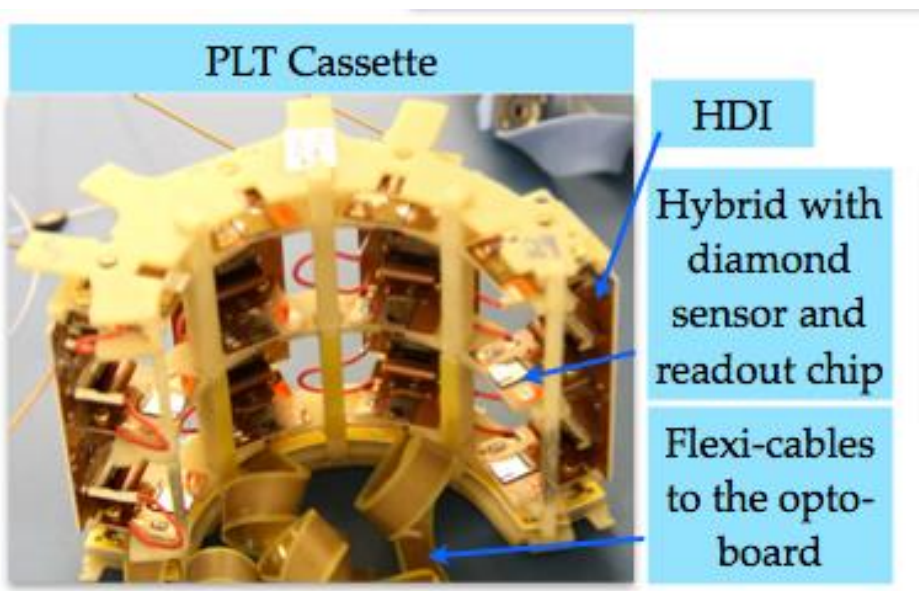
- Levels corresponding to addresses
- Represents where on the chip the data is coming from
- Level corresponding to collected charge
- Must be well separated to distinguish pixel address bits

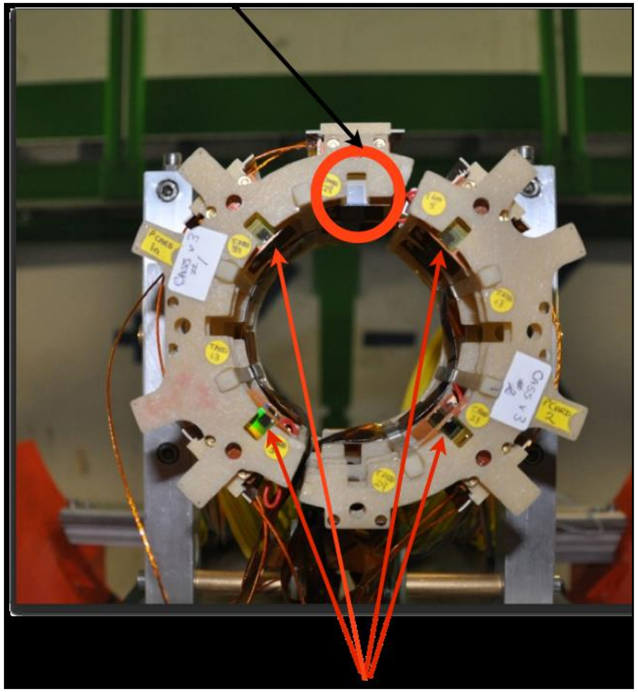




The Pilot Run in 2012

- Only two cassettes, ~half filled with sensors
  - Placed far from IP
- 4 diamond telescopes and one silicon telescope
- Meant to assess the viability of diamond as a detector material





Only 4 diamond telescopes for pilot run

BRILDAQ

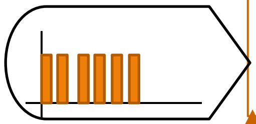
Takes PLT Histograms
runs code to produce plots
for end user

Readout occurs every 4096 orbits

PLT Readout

16 telescopes
3564 bin histogram each.
Each bin is an LHC “bucket”.

PLT Processor



Eventing Bus

All data sent to subscriber

All BRIL subsystems
and other luminometers
publish luminosity data,
sent downstream for analysis &
further processing

Local Control (UI)

+ database
- calibrations, masking
- detailed diagnostics
+ intermediate data storage: alignment, track based studies