Compact Muon Solenoid Detector (CMS) & The Token Bit Manager (TBM)

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Part 1: The TBM and CMS

- Understanding how the LHC and the CMS detector work as a unit

- Learning how the TBM is a vital part of the CMS detector

- Physically handling and testing the TBM chips in the Hi-bay

Motivation

- The CMS detector requires upgrades to handle increased beam luminosity
- Minimizing data loss in the innermost regions of the detector will therefore require faster, lighter, more durable, and more functional TBM chips than the current TBM 05a

We tested many of the new TBM08b and TBM09 chips to guarantee that they meet certain standards of operation.

CERN

Conseil Européen pour la Recherche Nucléaire (European Council for Nuclear Research) (1952)

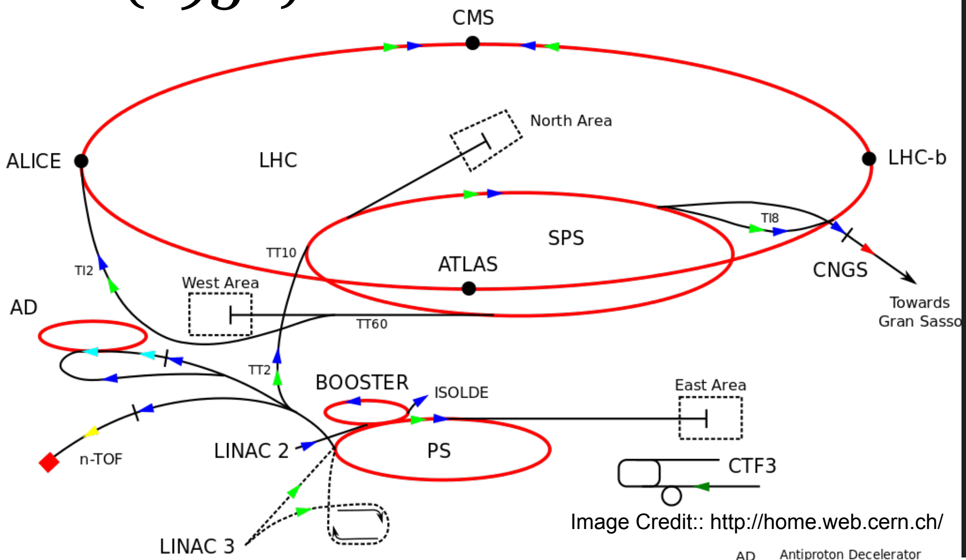


Image Credit:: http://home.web.cern.ch/

ACCELERATORS

- The Antiproton Decelerator
- The Large Hadron Collider
- The Proton Synchrotron
- The Super Proton Synchrotron
- CERN Neutrinos to Gran Sasso

EXPERIMENTS

ACE	COMPASS
AEGIS	DIRAC
ALICE	ISOLDE
ALPHA	LHCb
AMS	LHCf
ASACUSA	MOEDAL
ATLAS	NA61/SHINE
ATRAP	NA62
AWAKE	nTOF
CAST	OSQAR
CLOUD	TOTEM
CMS	UA9

CERN -> LHC

Large Hadron Collider (2008)

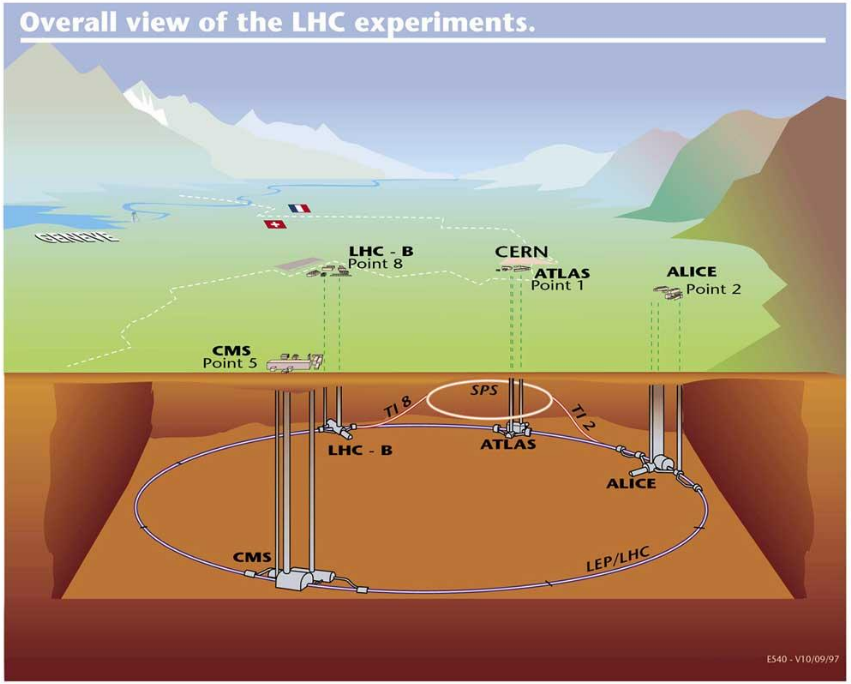


Image Credit: hep://home.web.cern.ch/topics/large---hadron---collider

Two proton beams travel in opposite directions until collision in detectors

1) ATLAS
2) ALICE
3) LHCb
4) CMS

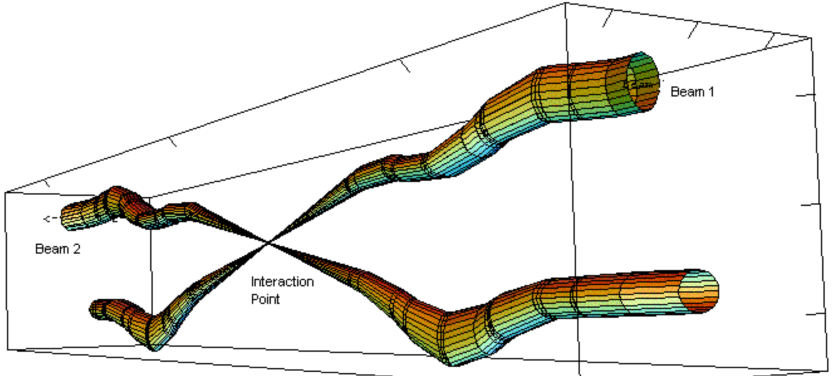


Image Credit: http://lhc-machine-outreach.web.cern.ch/lhc-machine-outreach/collisions.htm

CERN -> LHC -> CMS

Compact Muon Solenoid (2008)

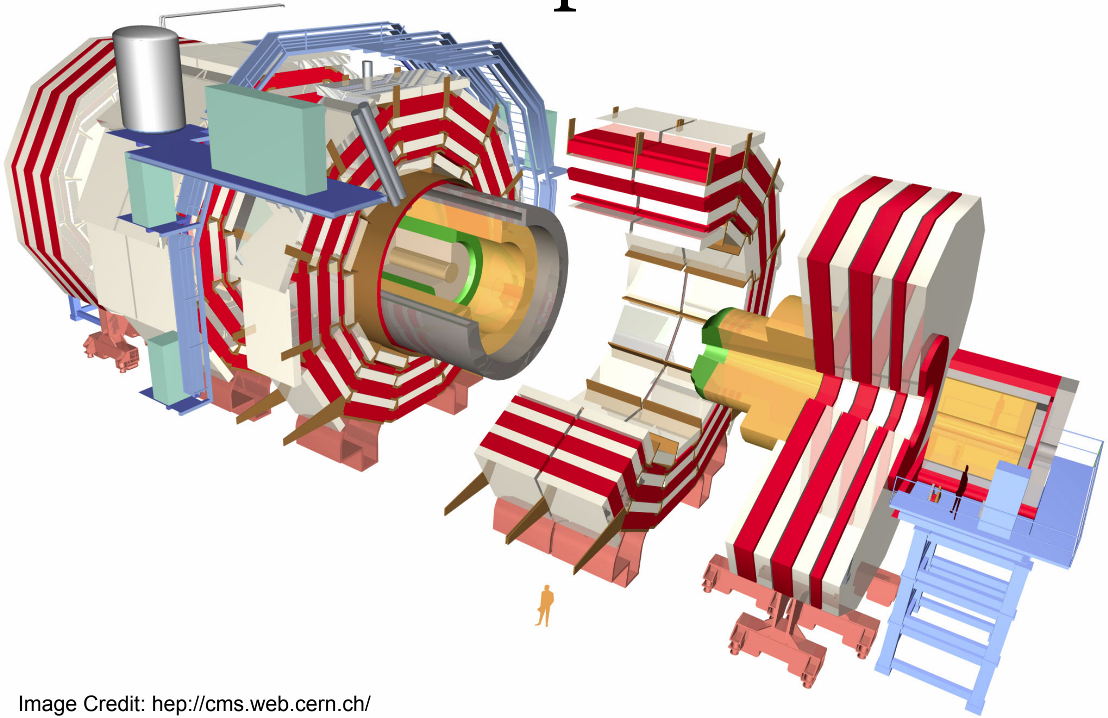


Image Credit: hep://cms.web.cern.ch/

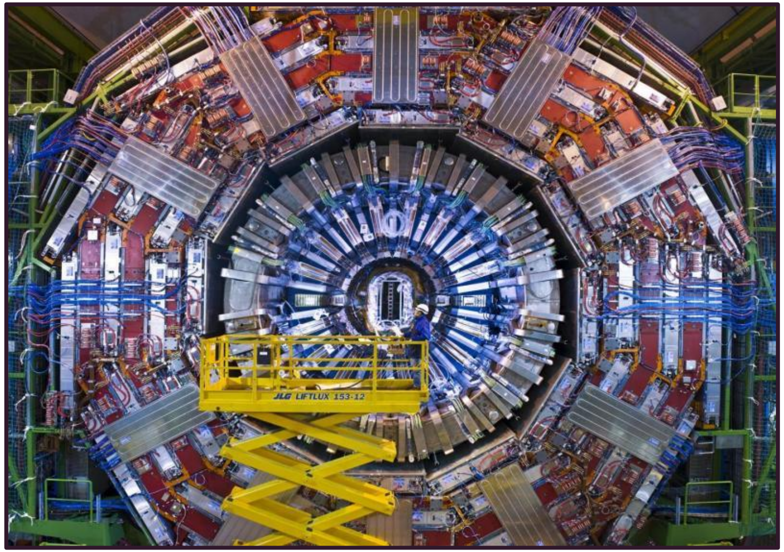


Image Credit: http://home.web.cern.ch/about/experiments/cms

CMS Detector System

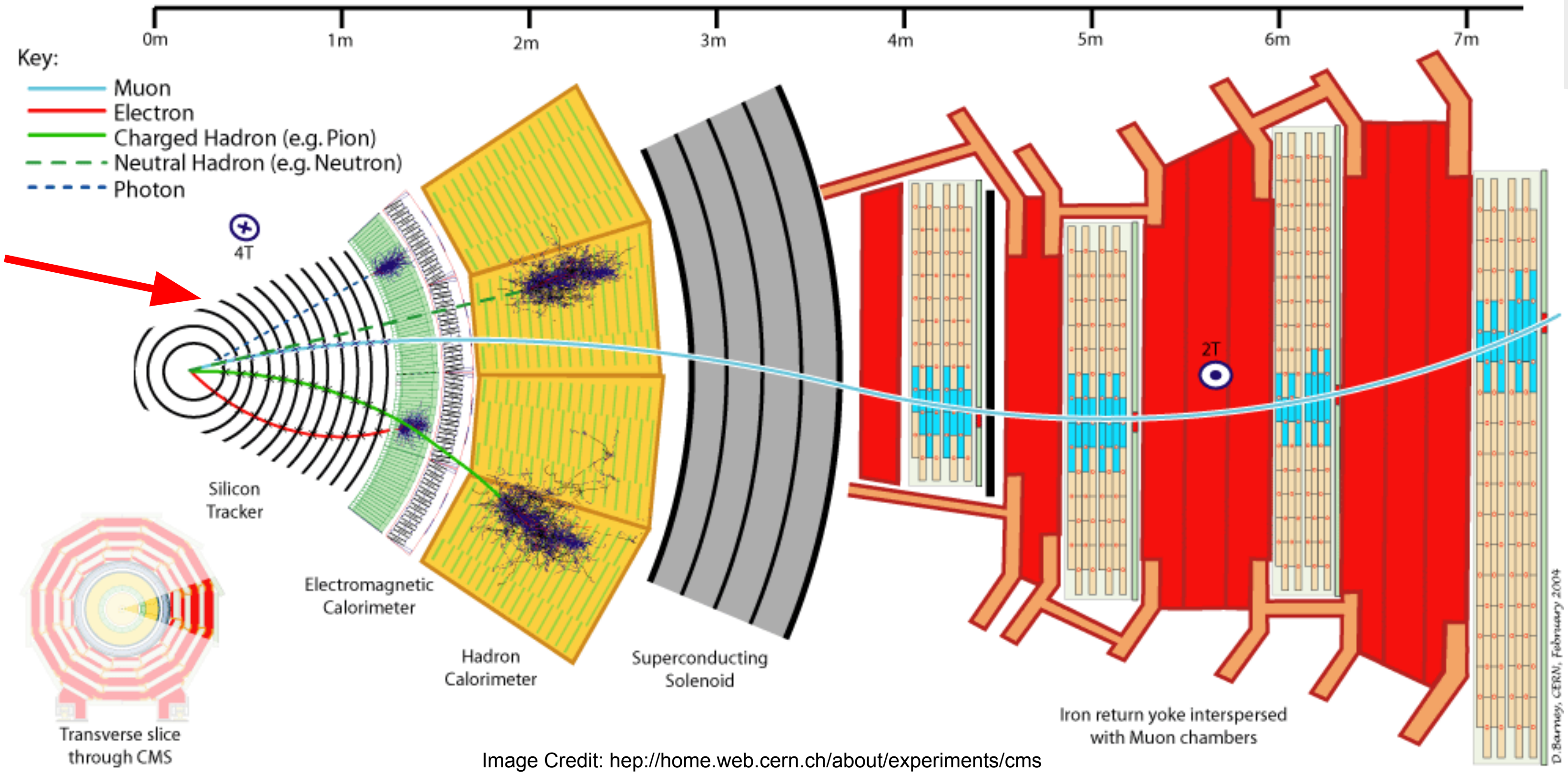


Image Credit: hep://home.web.cern.ch/about/experiments/cms

Inner Silicon Tracker

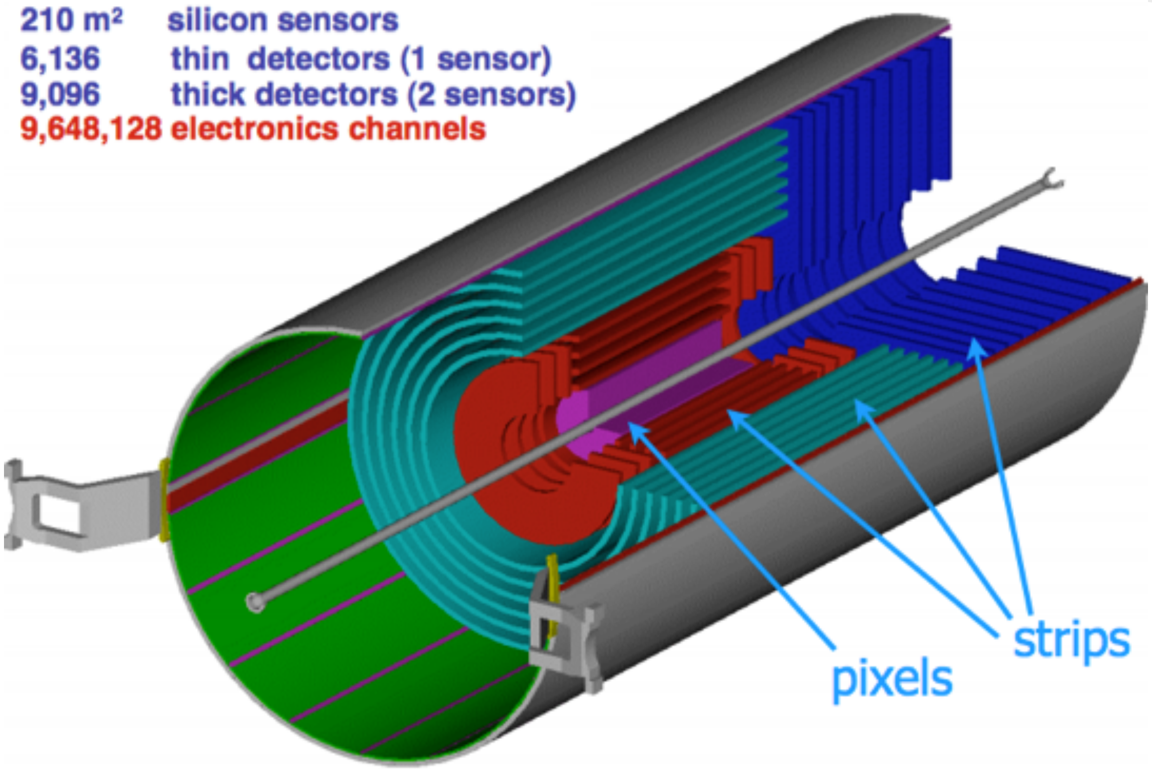


Image Credit: https://inspirehep.net/record/1234410/plots

Semiconductor detector technology used to measure and time stamp position of charged particles

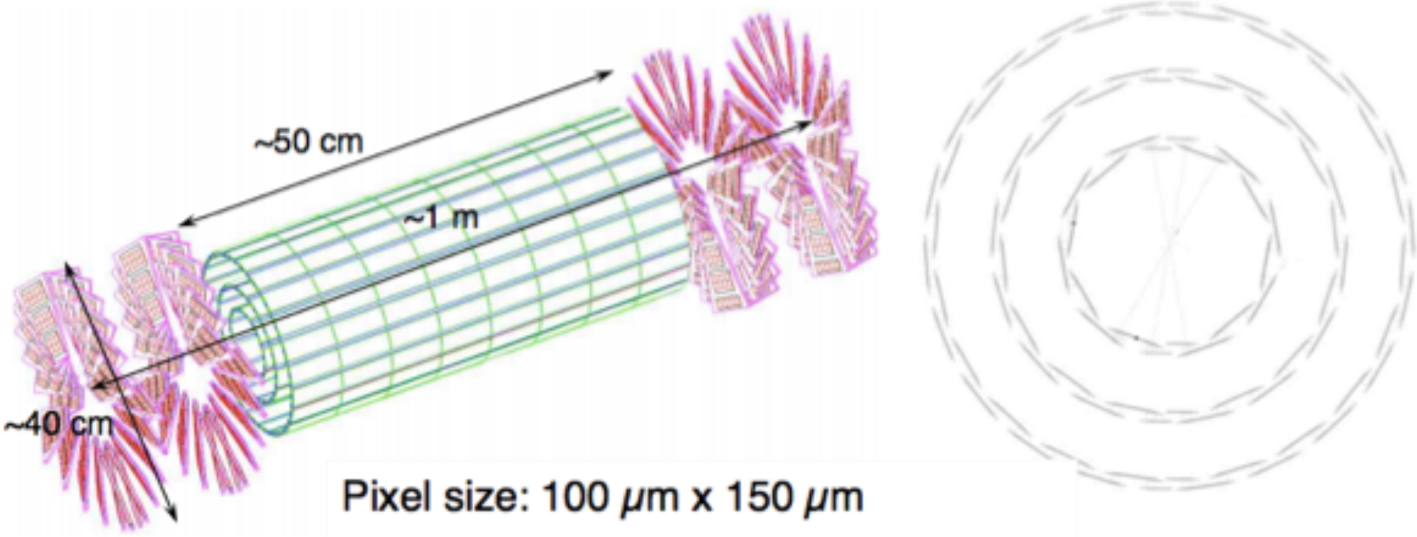
Inner layers consist of **pixels** for highest possible resolution

Outer layers consist of **strips** for lower production cost

Inner Silicon Pixel Tracker

The layers consist of individual **pixels** grouped into **modules** managed by the TBMs

Pixel layers provide the highest resolution data for positions of charged particle



Barrel Pixel:
3 barrel layers at *r* of 4.3, 7.3, 10.4 cm
11520 chips (48 million pixels)

Forward Pixel:
4 disks at *z* of ±35.5 and ±46.5 cm
4320 chips (18 million pixels)
Modules dilted by 20° for better charge sharing

Image Credit: CMS CR -2011/256

Inner Silicon Pixel Tracker

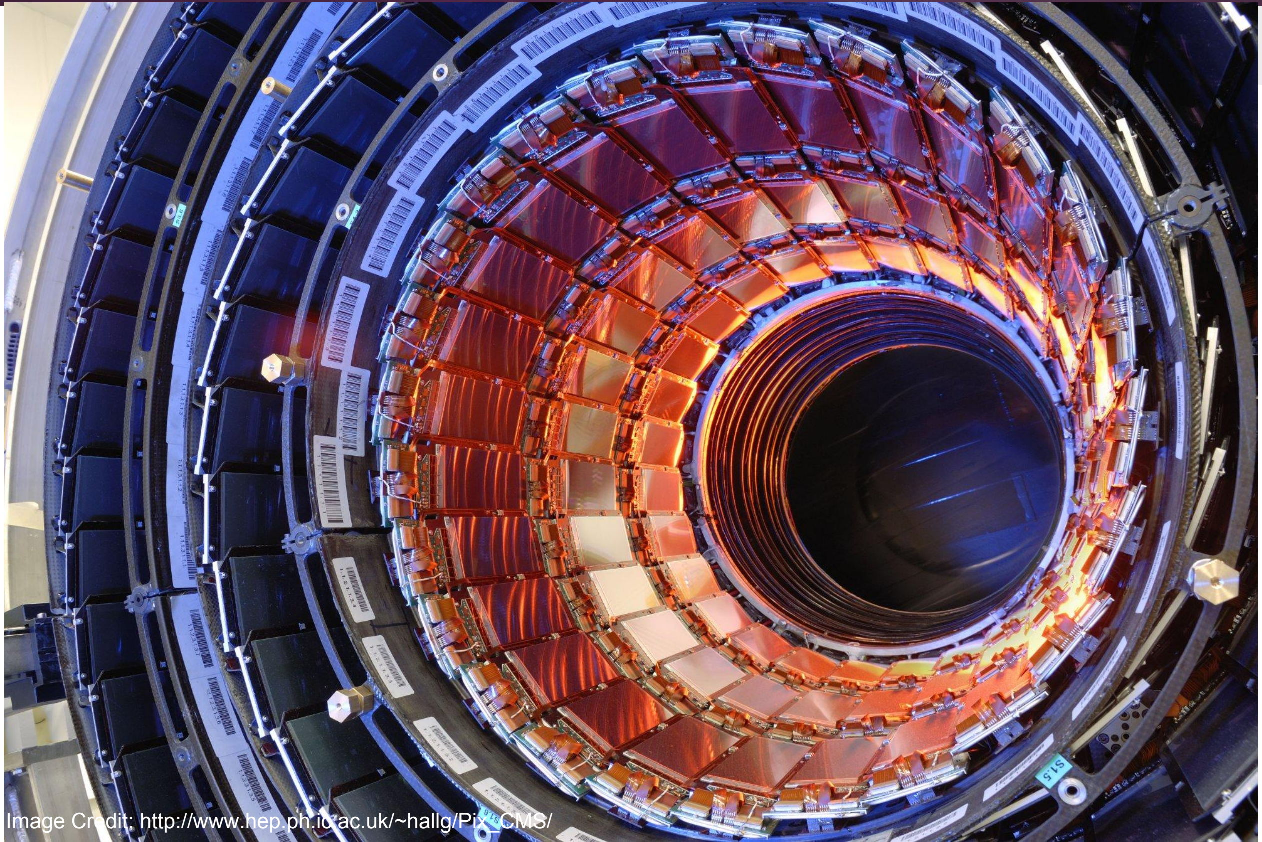


Image Credit: http://www.hep.ph.ic.ac.uk/~hallg/Pix_CMS/

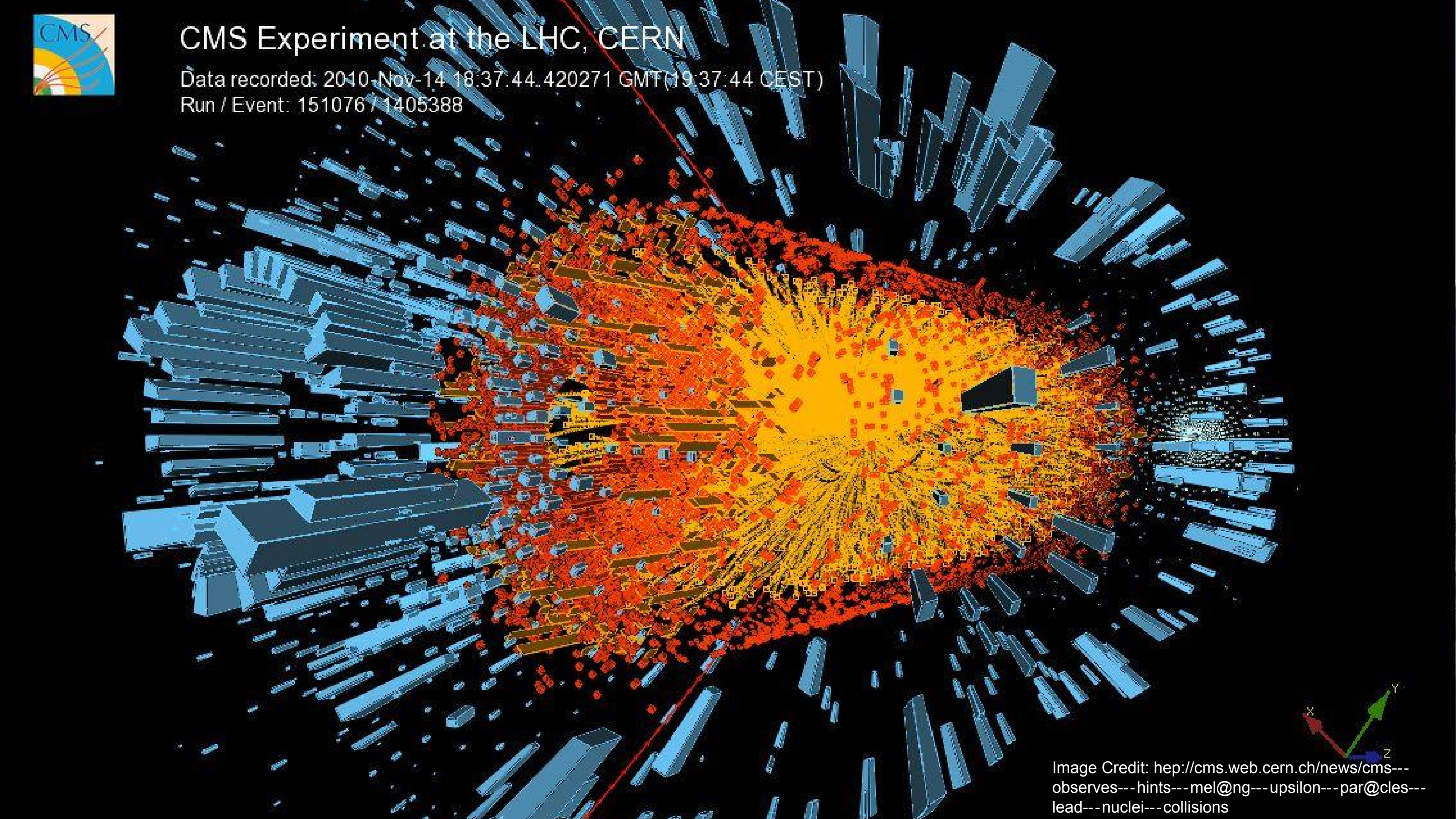


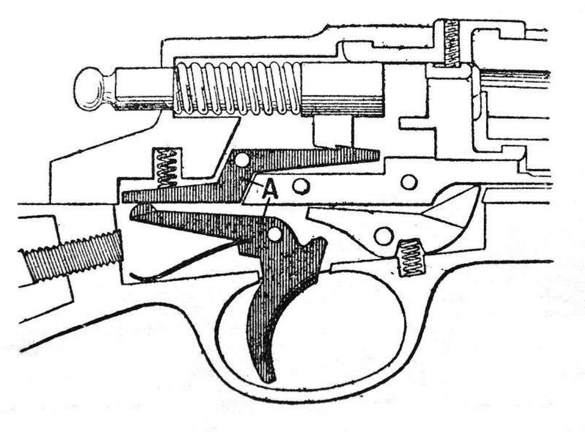
Image Credit: hep://cms.web.cern.ch/news/cms---observes---hints---mel@ng---upsilon---par@cles---lead---nuclei---collisions

Problems & Solutions

1) SO MUCH DATA! - 40 terabytes/second
    a. Level 1 trigger system (3500ns latency)
    b. Higher level trigger system

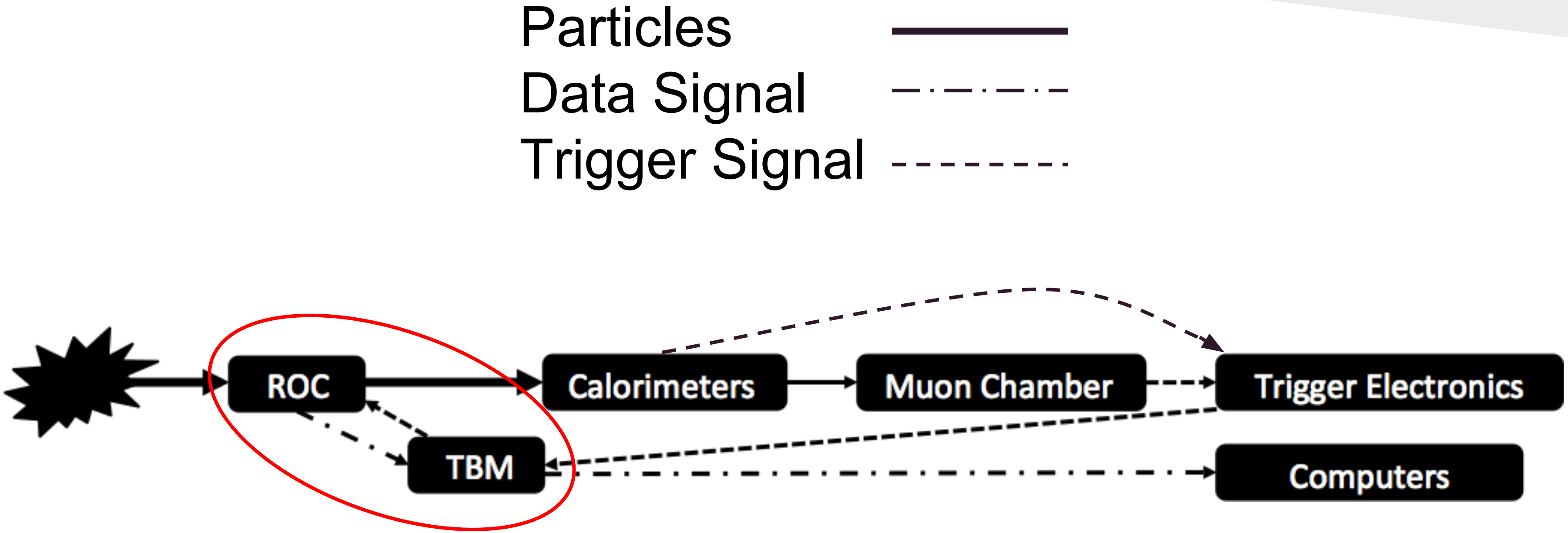
2) High Collision Rate - 40 MHz (25ns gap)
    a. Buffer zones in ROCs
    b. High time resolution

Level 1 Trigger



- Completely Automatic - No Software
- Selects ~1/10,000 hits
- The Selection Process:
    1) Detection by Calorimeter and Muon Chambers
    2) Trigger Electronics selects desirable events
    3) Acceptance/rejection trigger sent to TBM
    4) TBM sends message to ROC to collect or discard
    5) Collected messages are sent downstream

From Scatta to Data



What Makes A Module?

- The ROCs are the base for the silicon pixel sensor
- The TBM is integrated directly onto the circuit above the sensor
- 3 layers of pixel detectors will form the Inner Tracking Level

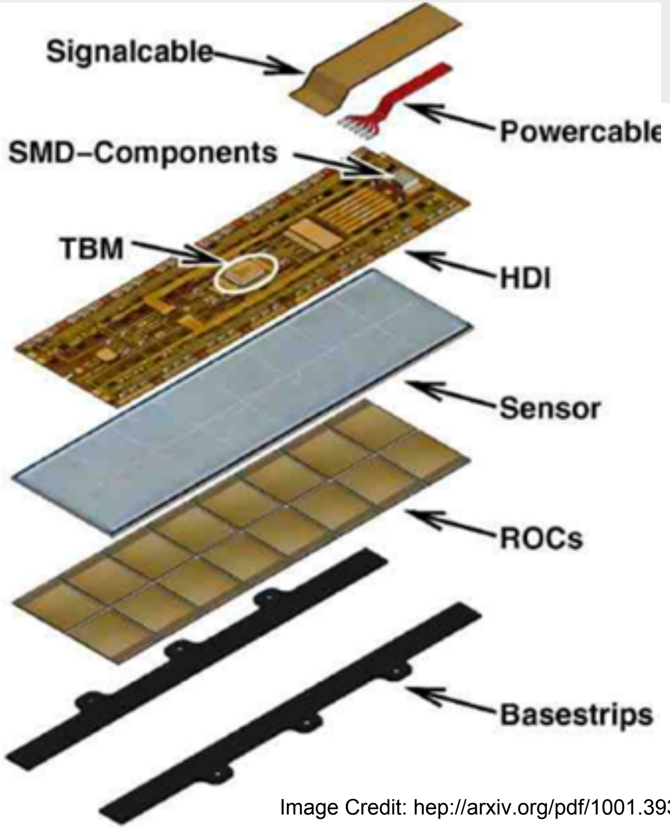


Image Credit: hep://arxiv.org/pdf/1001.3933.pdf

The Pixels/ROC Data Storage

- The Inner Tracking Detector has approx 48 million pixels
- Each silicon sensor is only 150 x 100 µm (about 2 hair widths)
- The ROCs keep their time-stamped information until they are cleared to release to the data stream

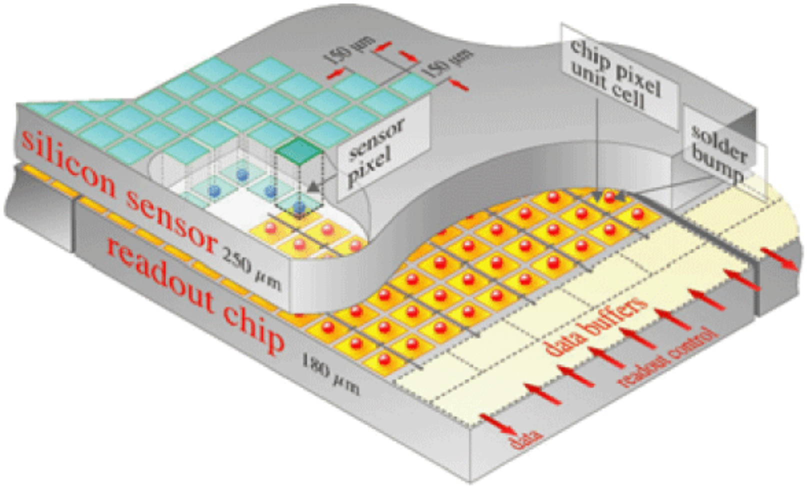


Image Credit: hep://cms.web.cern.ch/news/silicon---pixels

Pixel Detectors/Modules

- The TBM chip (shown below) is used to manage ROC's data release and reset

- [This picture displays a TBM connected to 16 ROC (read out chips)]

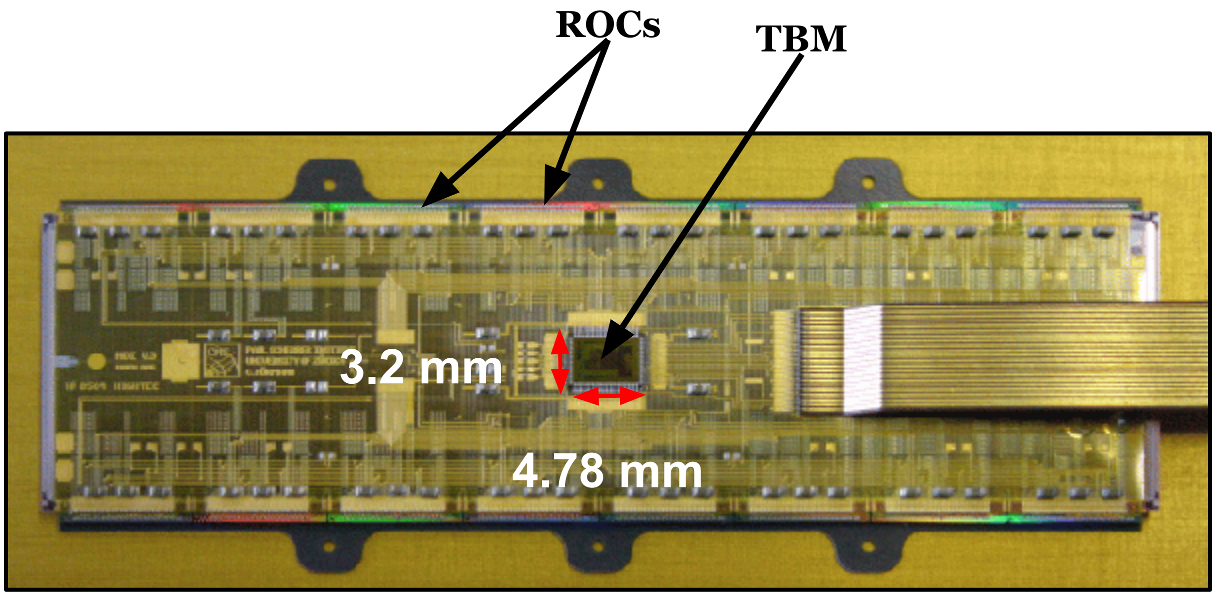
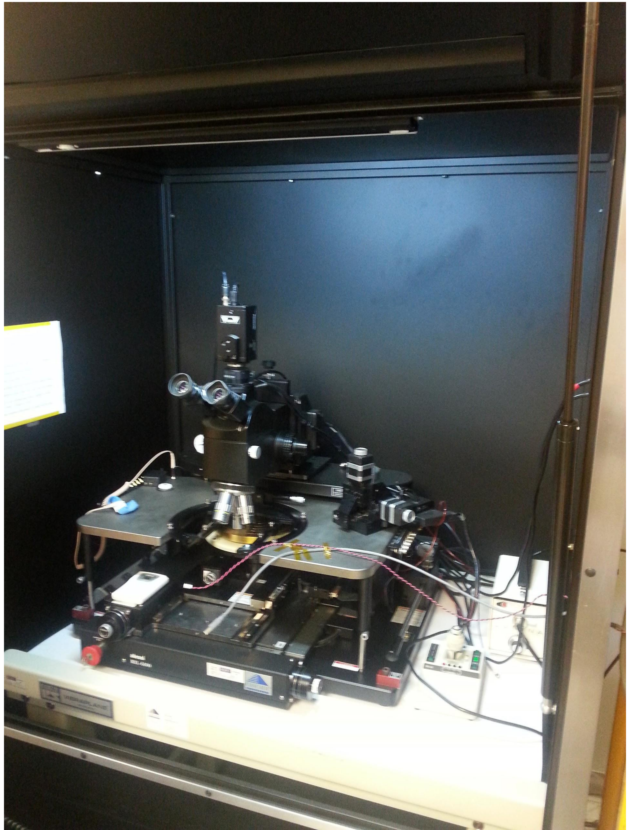


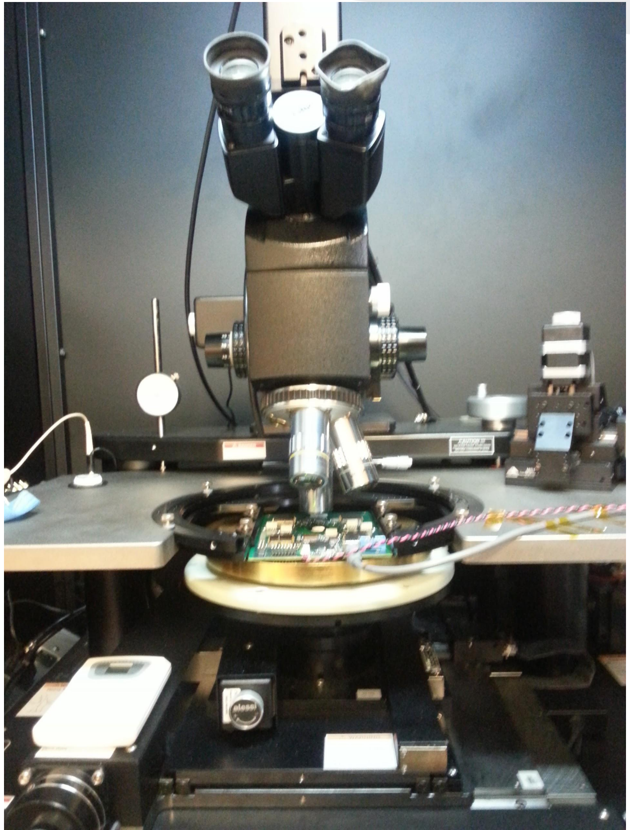
Image Credit: hep://arxiv.org/Hp/arxiv/papers/0707/0707.1026.pdf

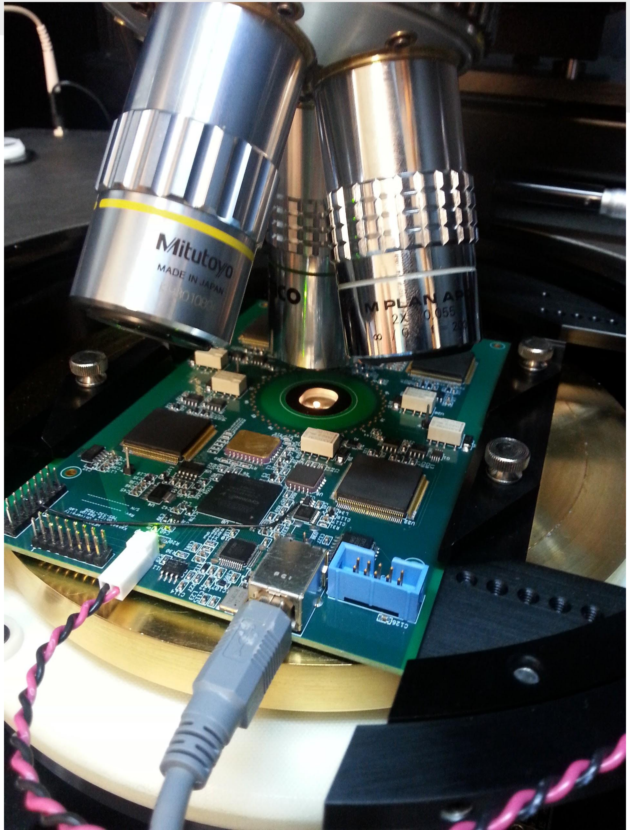
The TBM and Token Passing

- The TBM uses a “token” to control and convey information to the ROCs
- The token is also used by the TBM to register the state of each ROC
- TBMs send tokens through the ROCs before acquiring data, if the token is not returned to the TBM in a certain time interval, the event is labeled a “No Token Pass” and the ROCs clear their data buffers
- The TBMs are a direct line of communication between the detector and the LHC operators above CMS

Testing the Chips - The Setup



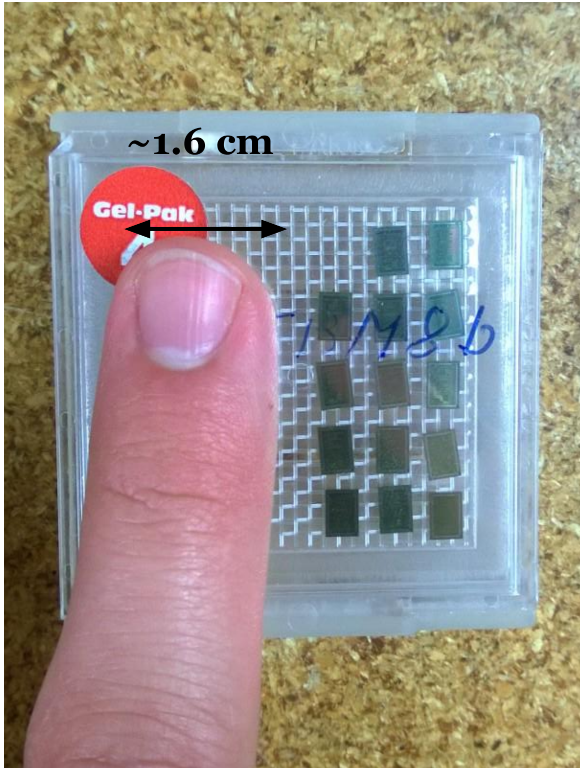


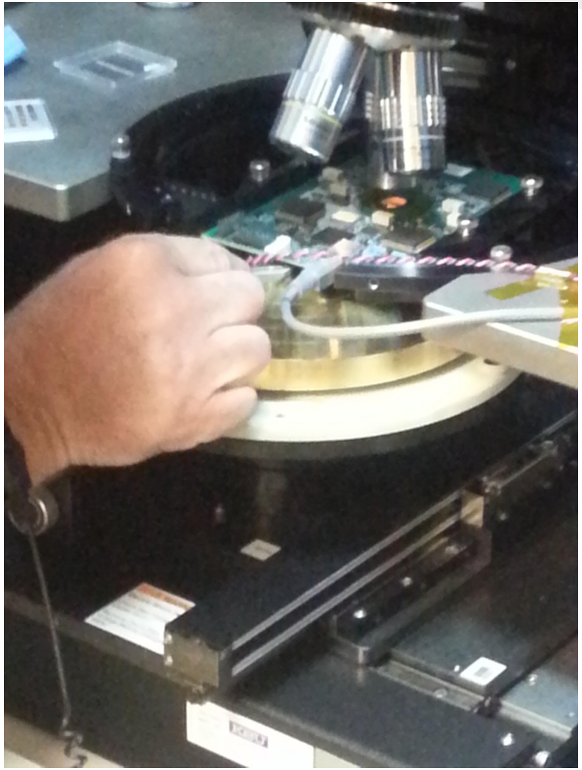


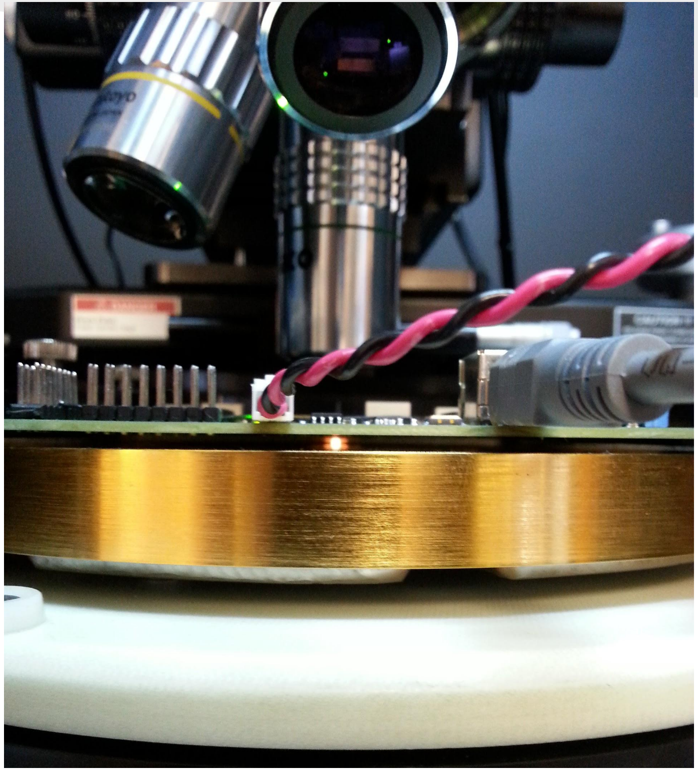
Hardware & Calibration

- Using Cascade Probe Station and Nucleus 3.2 Interactive Software
- The stage (or chuck) moves freely beneath a stationary testing board that contains a probing zone
- The wafer is placed on the chuck and raised up to the board to make a connection and run tests (Note: Only 50 µm of freeplay are allowed when making connection)
- Some issues with the chuck being unbalanced could lead to crashing the probe

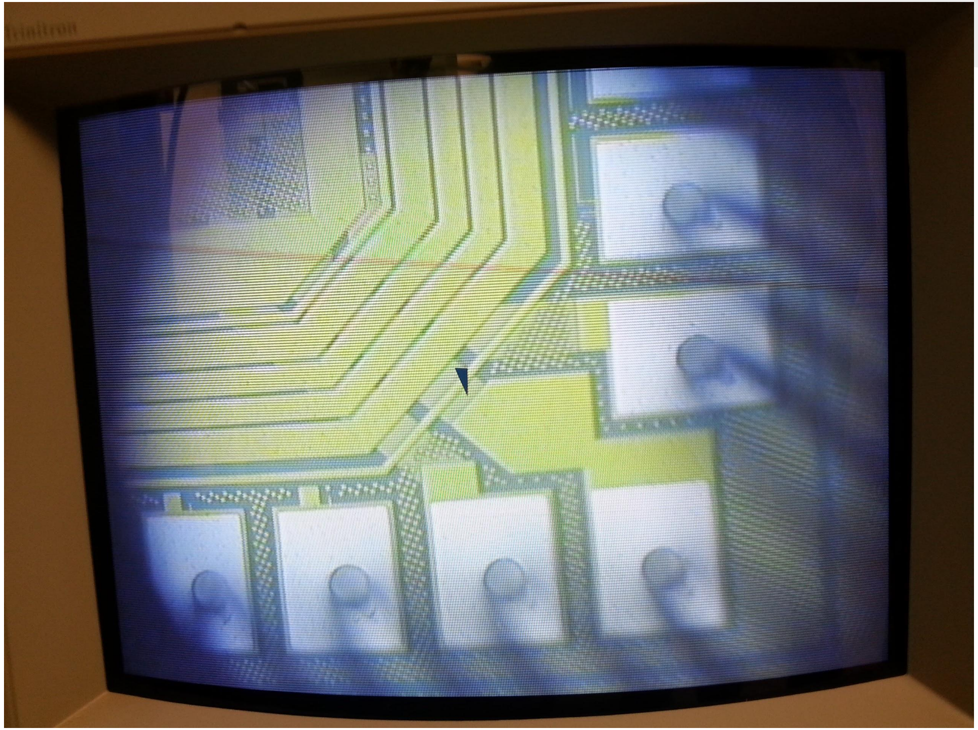
Putting on a Single TBM Chip







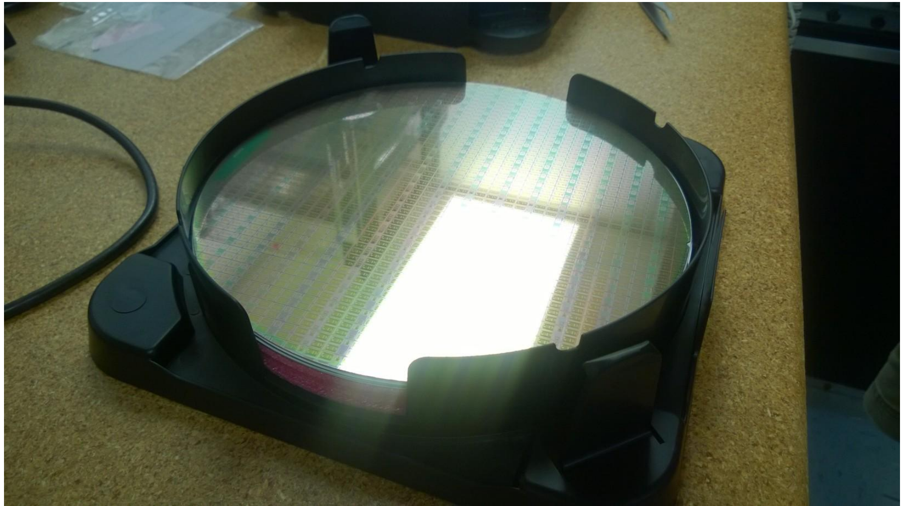
Aligning the Probe



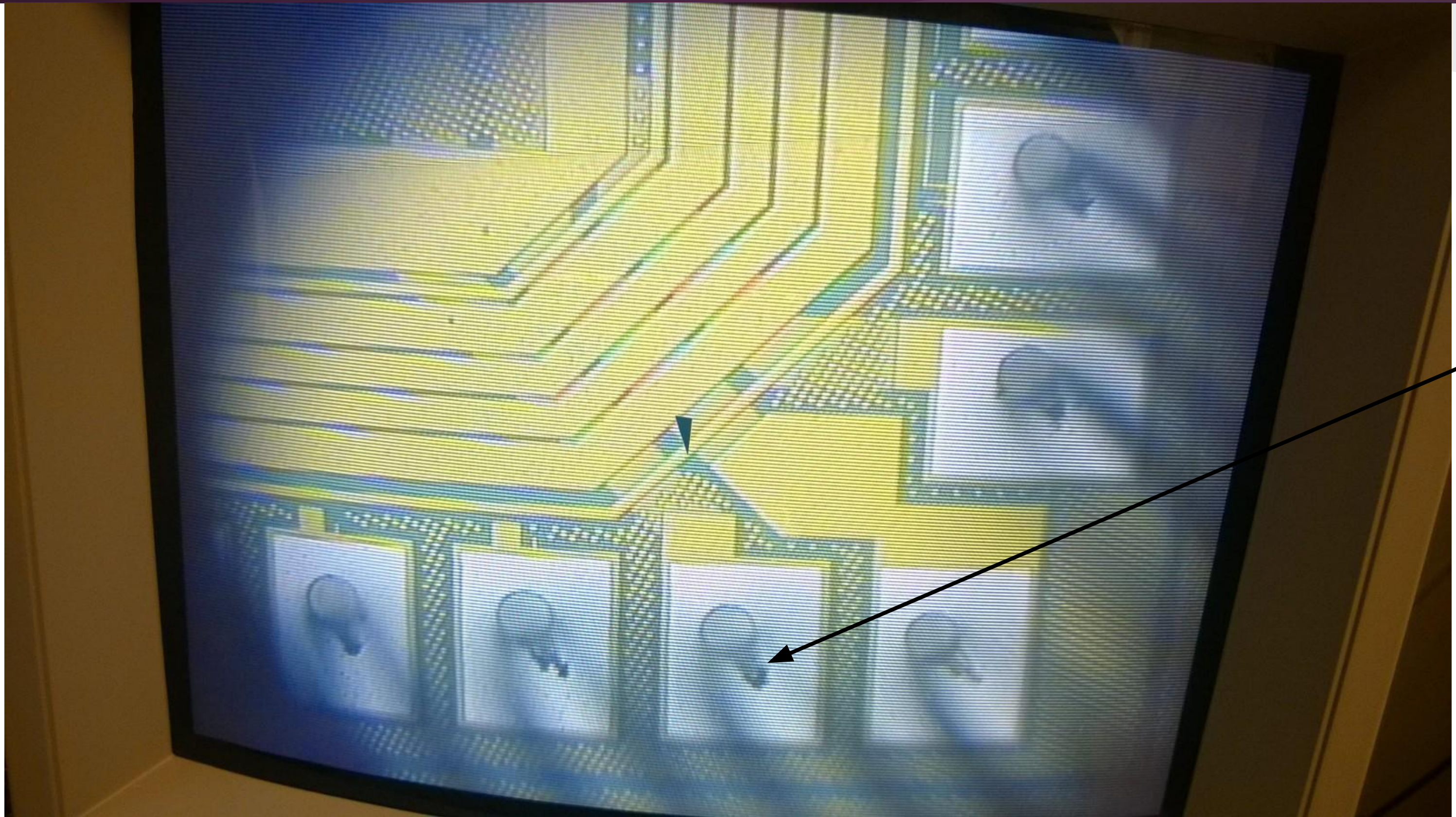
Testing Wafers

- Contain thousands of TBM chips

- 200 mm diameter wafer with 3 different types of TBM chips on it

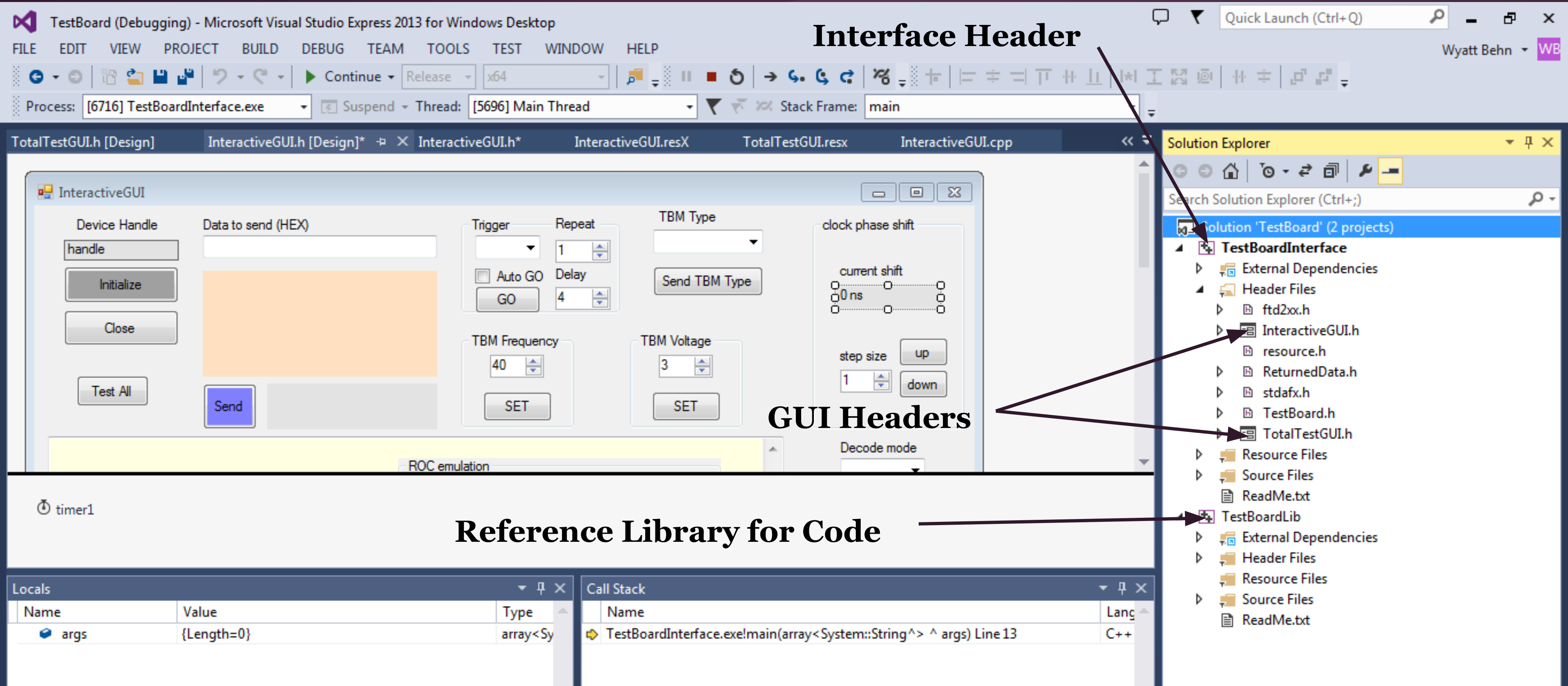


Making Contact



Scratches
Indicate Clear
Contact

Running the Test Code



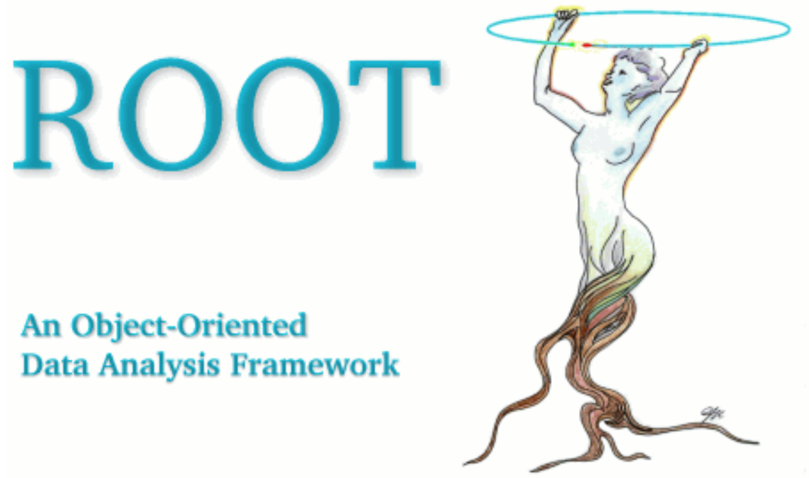
Summary of New TBM Benefits

- TBM 09 is digital, whereas the current version is analog (TBM 05a)
- The TBM 09 uses two TBM 08b cores that it splits between the ROCs, this allows for a more precise control when analyzing malfunctions
- Because the ROCs are distributed, the control room can reset certain ROCs without resetting a whole module (this is good for testing issues)
- The TBM 09 is more radiation resistant and also has the benefit of being made of less material which interferes with possible particle detection far less

Part 2: Coding

- Work with the programming language of C++
- Using the data analysis framework ROOT to interpret simulated data
- Using these two in tandem to create small programs that create useful interpretations of data

Analyzing the Data



Data analysis framework used to effectively store, recall, and analyze the large amounts of data output by the LHC

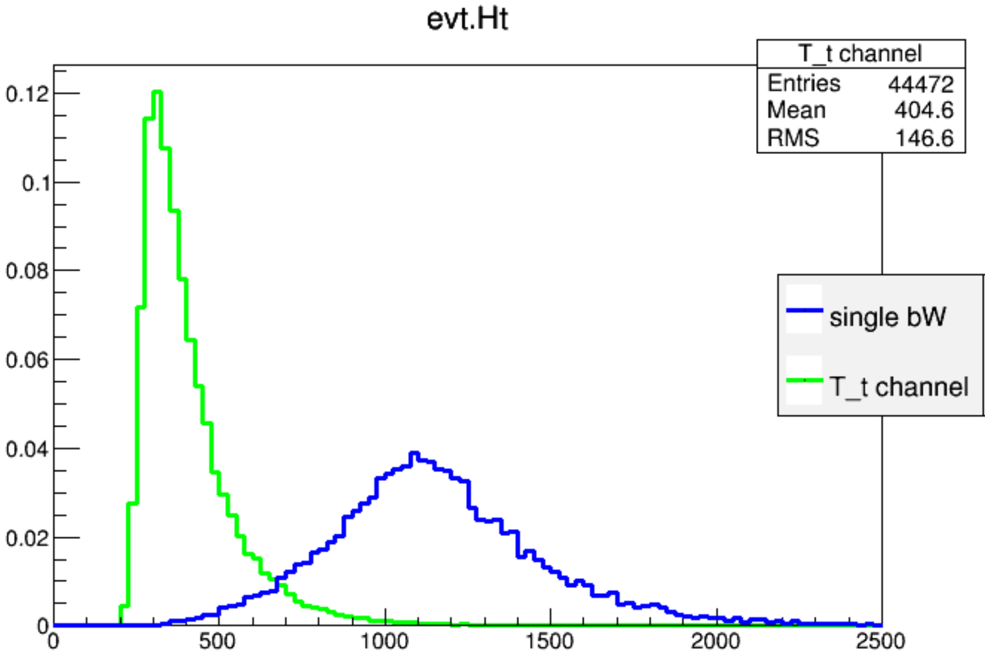
Data Analysis - Simulation

- Simulated data is used to show how possible particle collisions and outcomes may play out
- Simulations also help to show discrimination between theory and experimental result
- Comparing theoretical vs. experimental allows us to look for new and exciting things

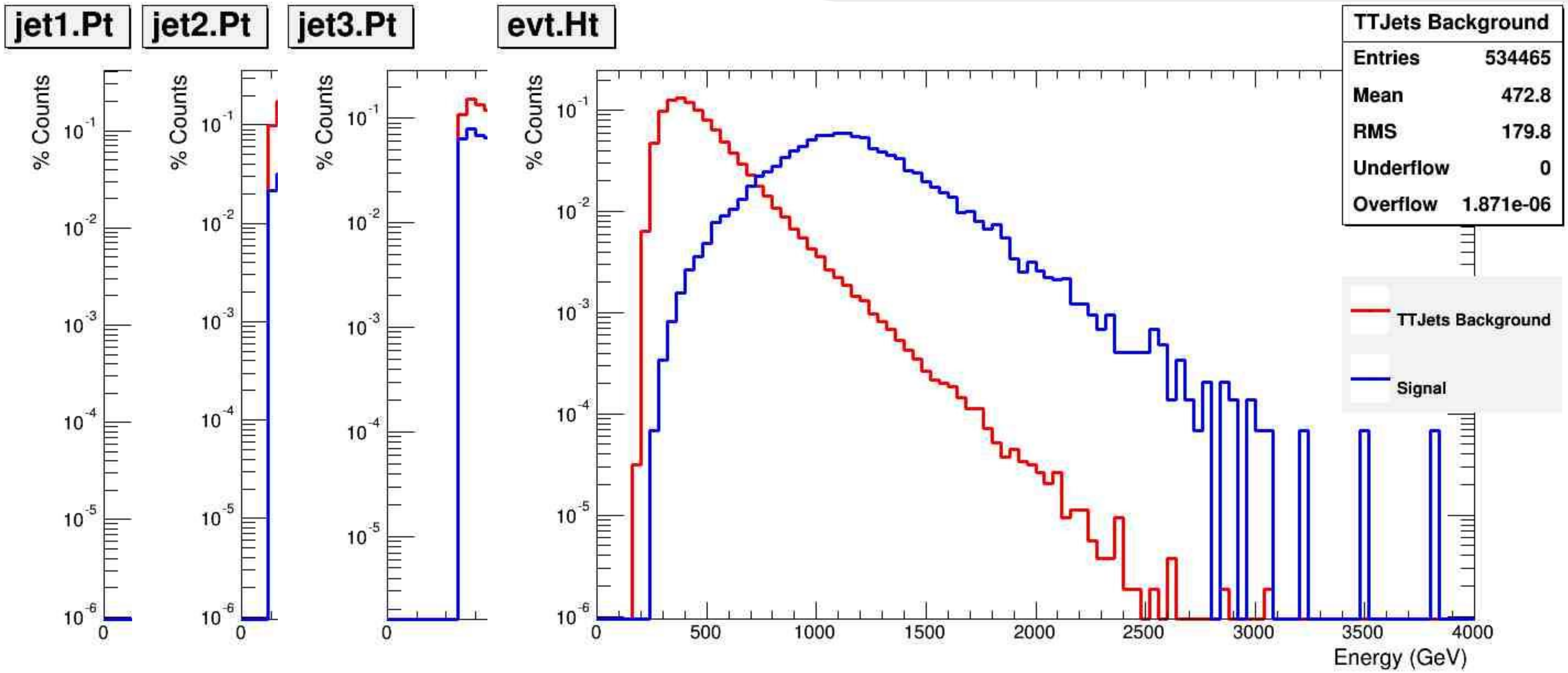
Signal vs. Background - Ex.

- This is an example of the total energy of a top anti-top particle creation event

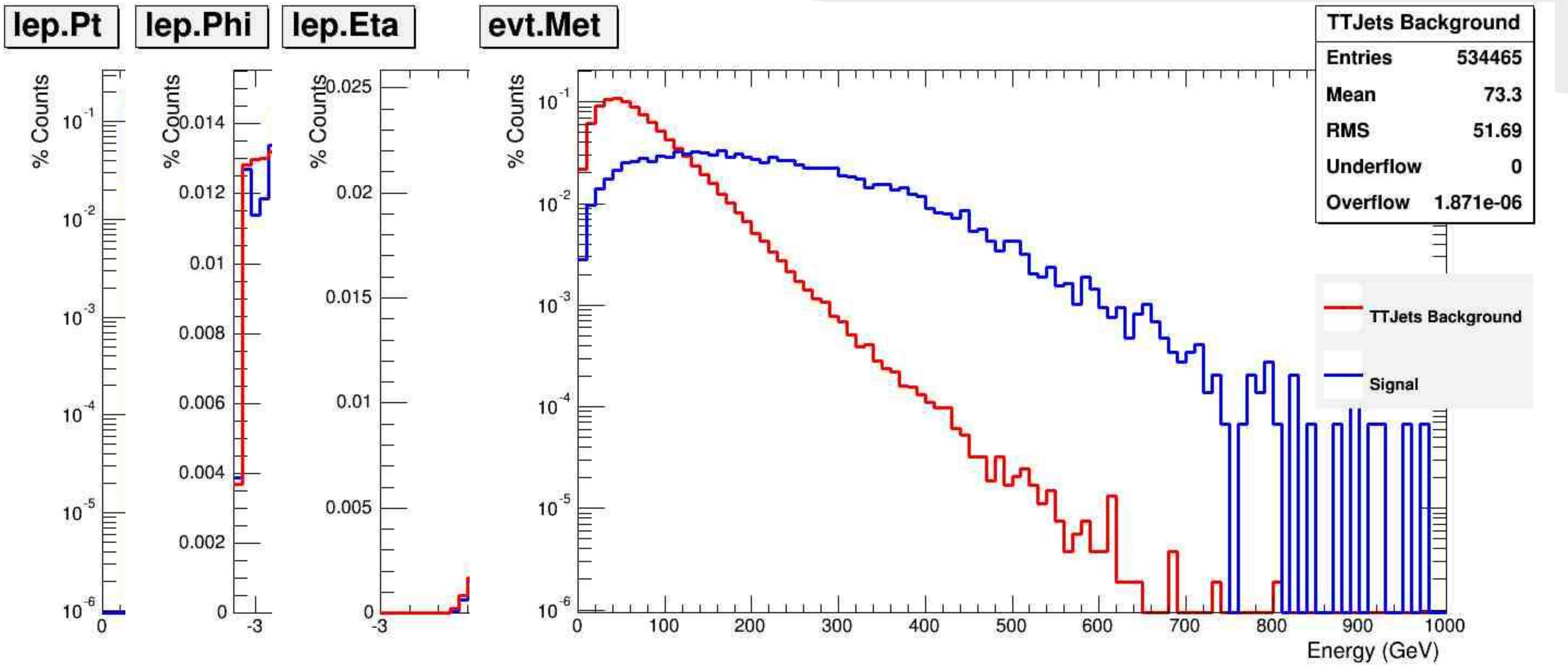
- The green background is clearly different from the blue signal information



Interesting Jets



Interesting Leptons



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