LHCb Upstream Tracker upgrade and its off-detector electronics

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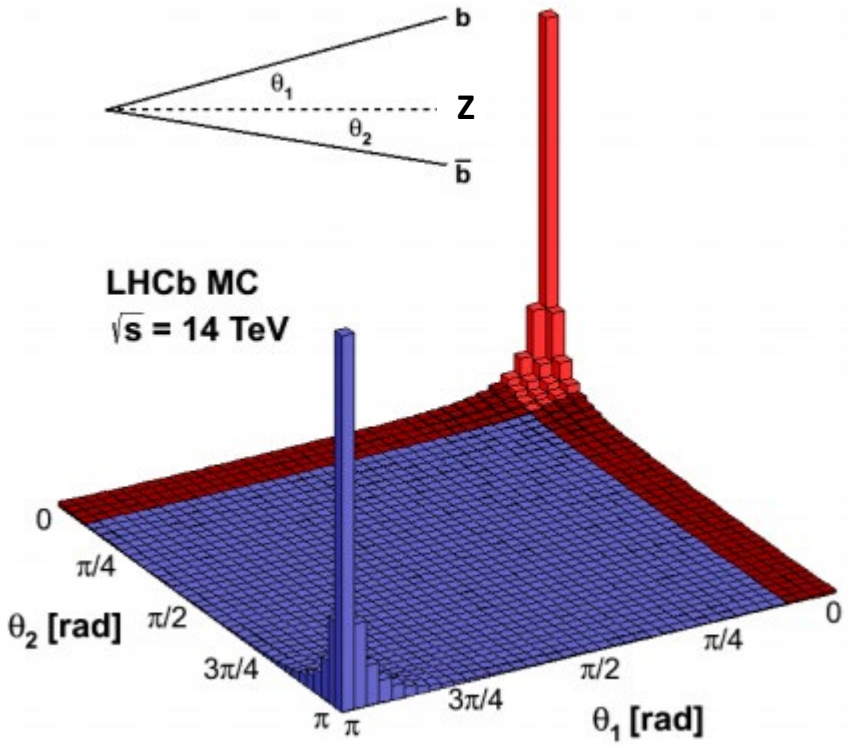
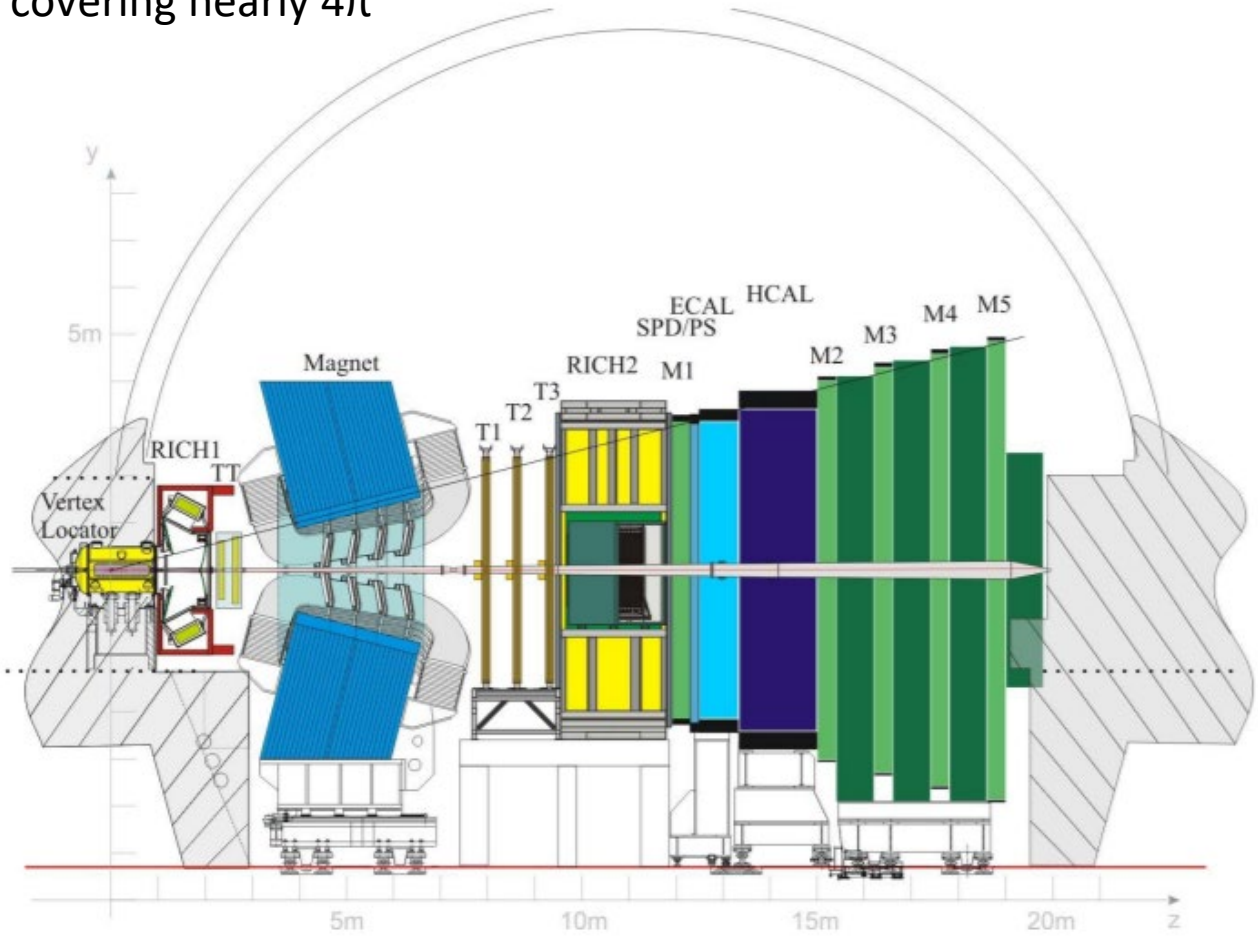
LHCb Detector

- Designed to study CP violation and search for new physics in the heavy flavor sector
- Beauty and charm dominantly produced in highly-boosted center-of-mass frame
- Detector accepts 25% of $b\bar{b}$ pairs by covering ~4% of the solid angle ($2 < \eta < 5$)
  - compared with ATLAS & CMS covering nearly 4π

$\sigma_{inel} \approx 70$ mb (13 TeV)

$\sigma_{b\bar{b}} \approx 550$ μb (13 TeV)

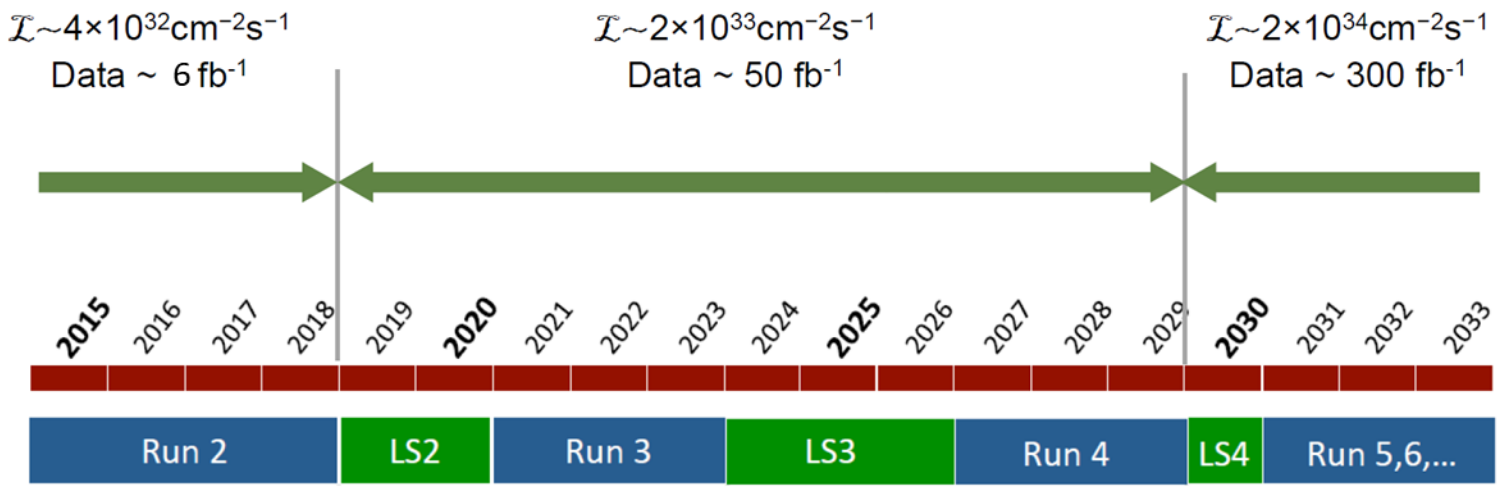




LHCb Upgrade

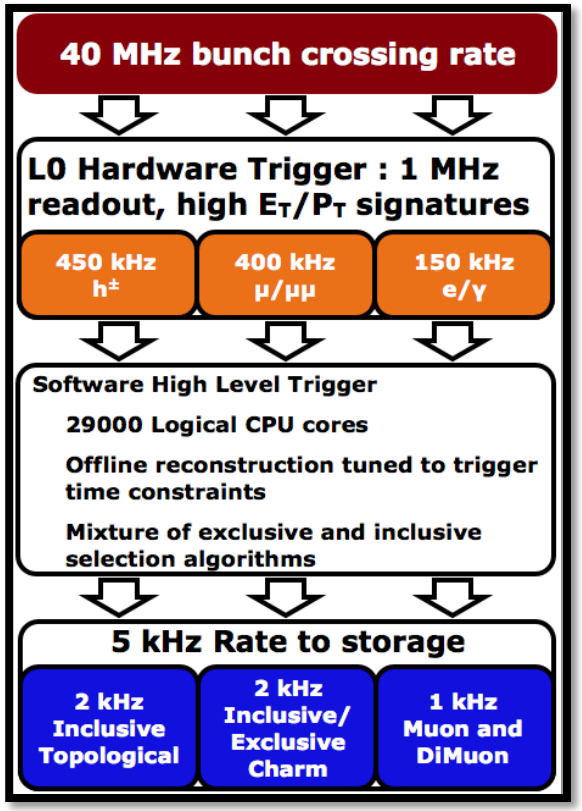
- Run III of LHC is scheduled to begin in 2021
  - Instantaneous luminosity at LHCb will increase by a factor of 5, to 2 x 10^{33} $cm^{-2}s^{-1}$
  - Plans to collect 50 fb^{-1} of integrated luminosity by 2030 (vs ~9 fb^{-1} in Run I + Run II)

- LHCb will be upgraded for Run III and beyond
  - to handle higher instantaneous luminosity
  - to operate without hardware trigger

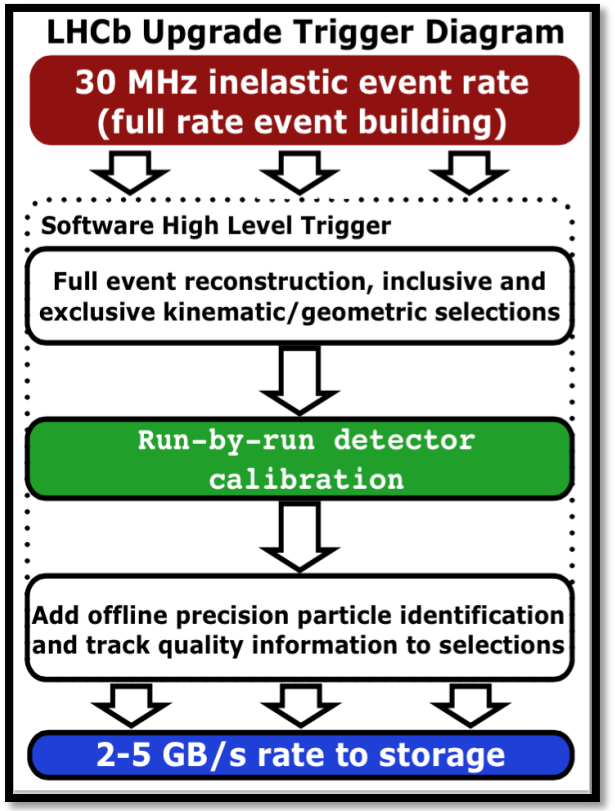


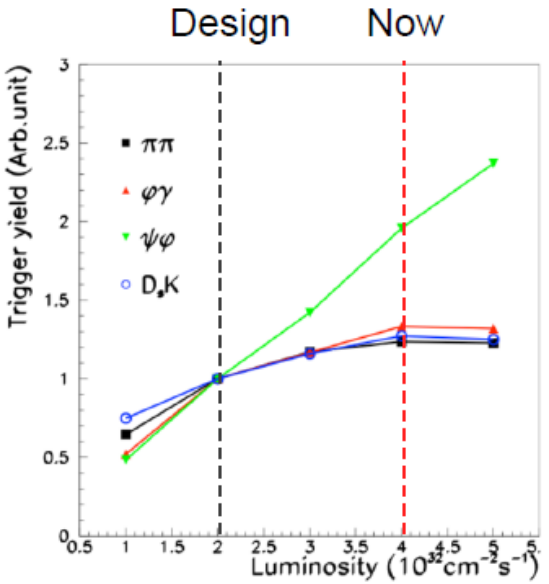
Trigger Upgrade

- Current hardware trigger output at 1MHz
  - limited by detector's readout speed



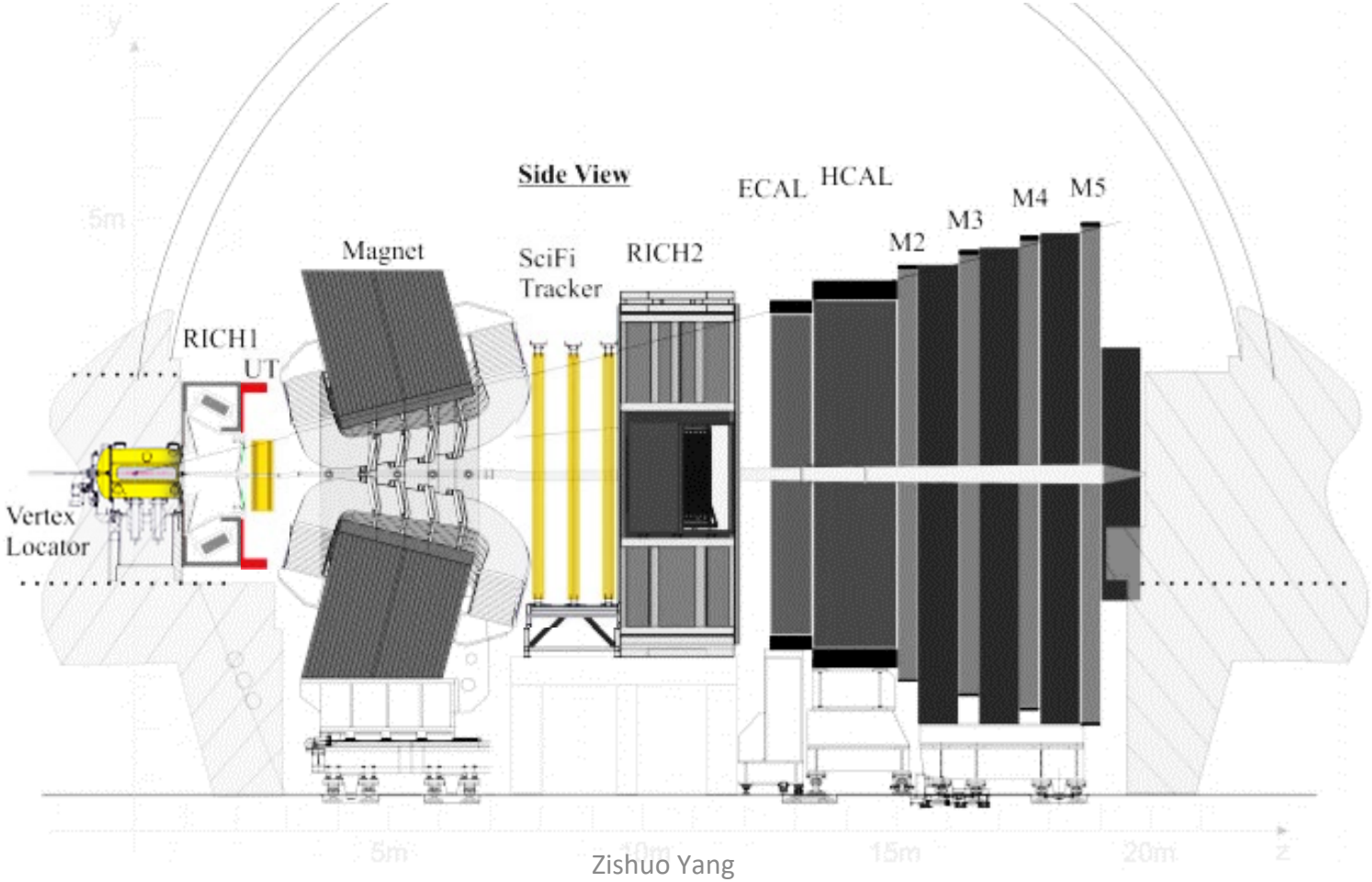
- Upgraded LHCb will be **read out at 40 MHz**
  - allows software-only trigger for high flavor-physics efficiency





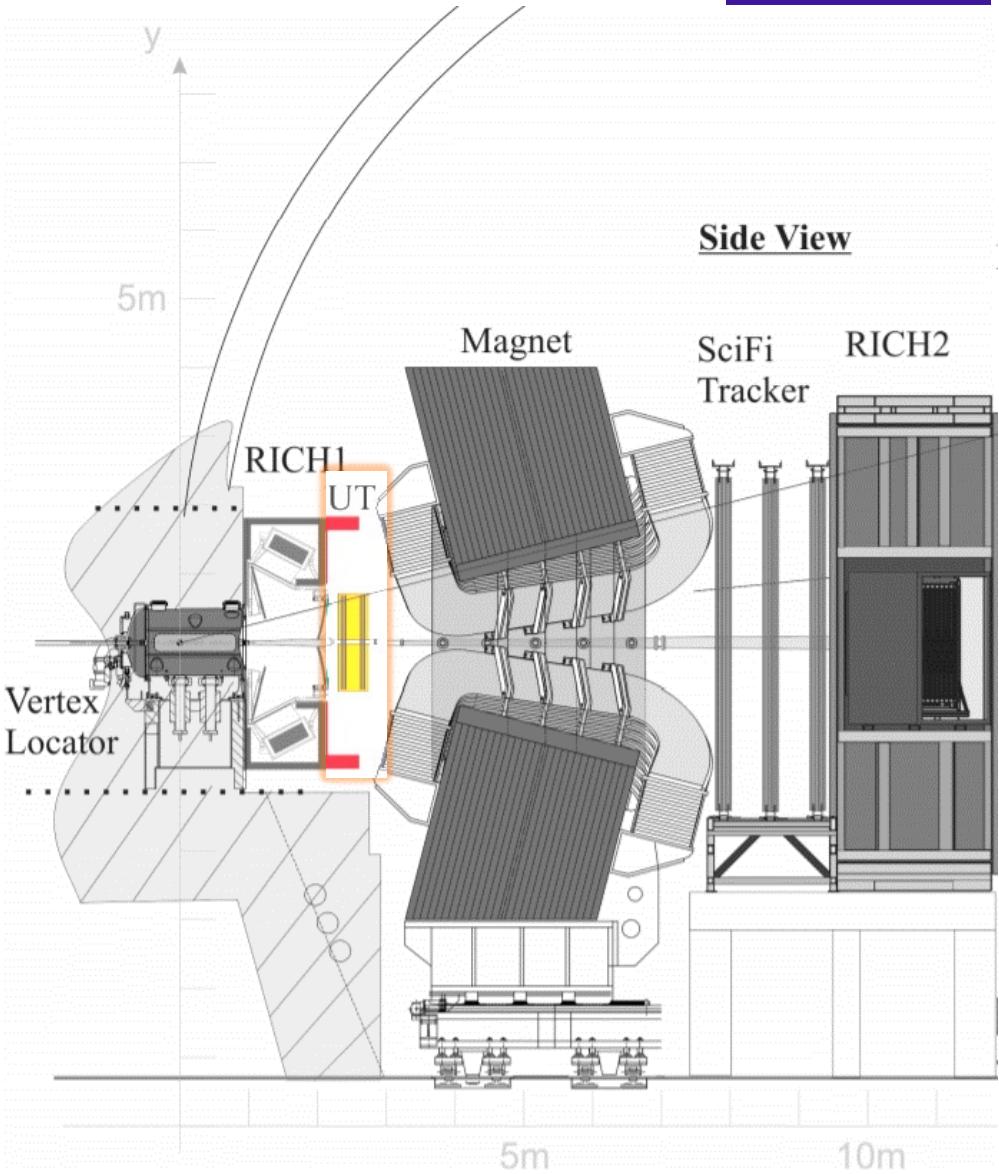
Upgraded Detector

- New tracking system
- 40 MHz readout capacity for the entire detector
- Improved Particle Identification system

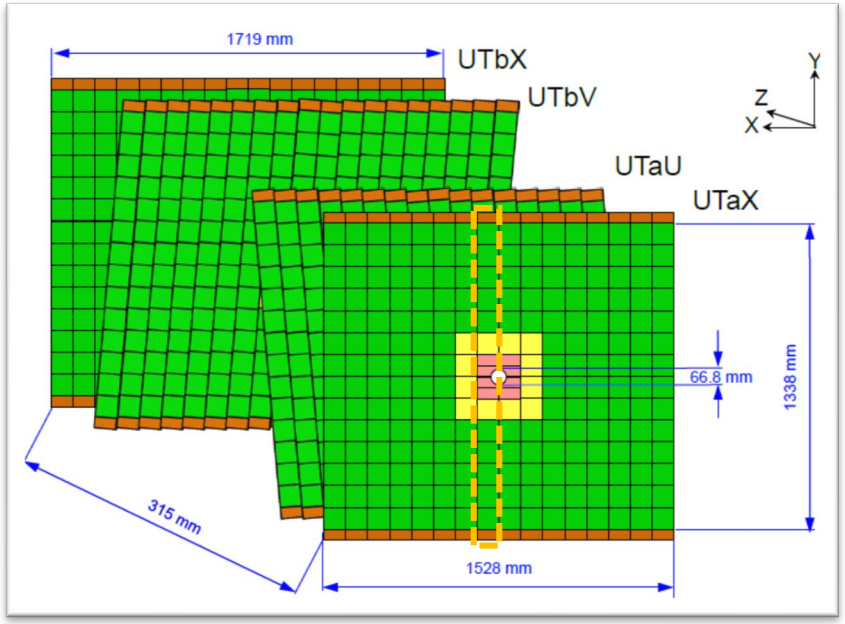


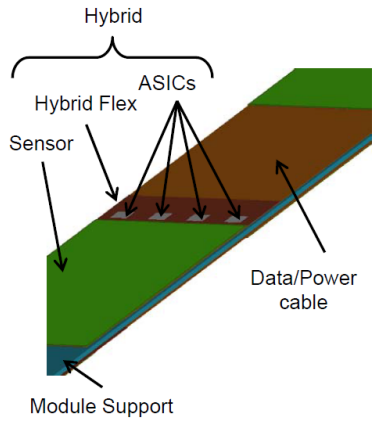
The Upstream Tracker (UT)

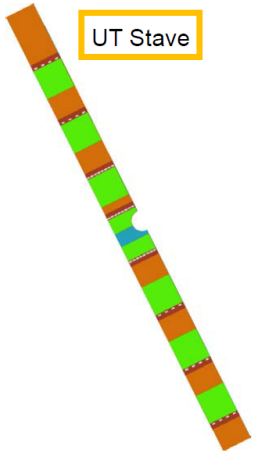
- U.S. led project
- Located upstream of the magnet
- Essential for fast triggering
  - Position between VELO and SciFi Tracker helps reduce ghost tracks
  - Fringe magnetic field allows fast momentum measurement of tracks
  - Increase speed of tracking in the trigger by a factor of three (for extrapolating VELO tracks to Tracking Station search window)
- 40 MHz readout capacity



UT Design



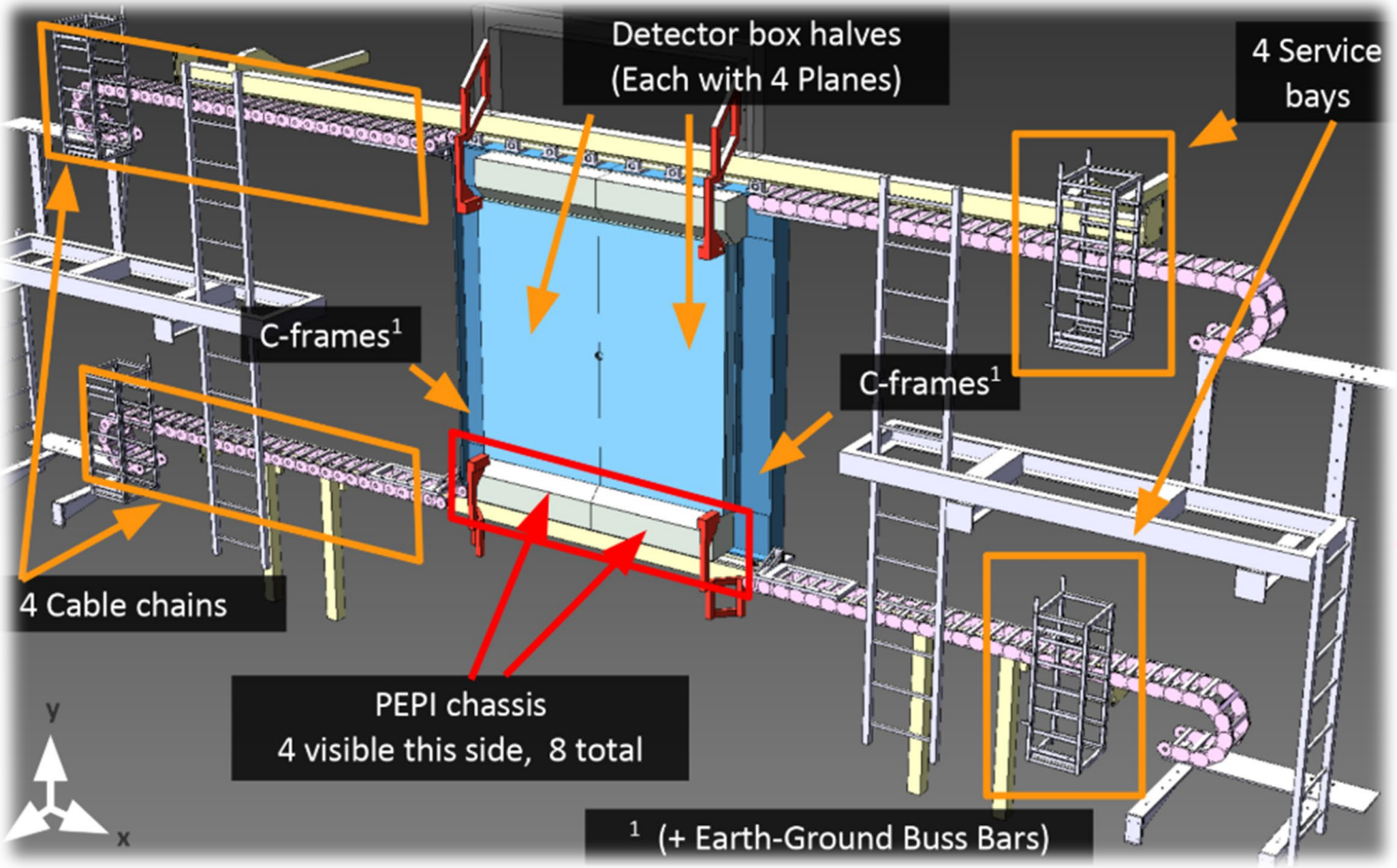




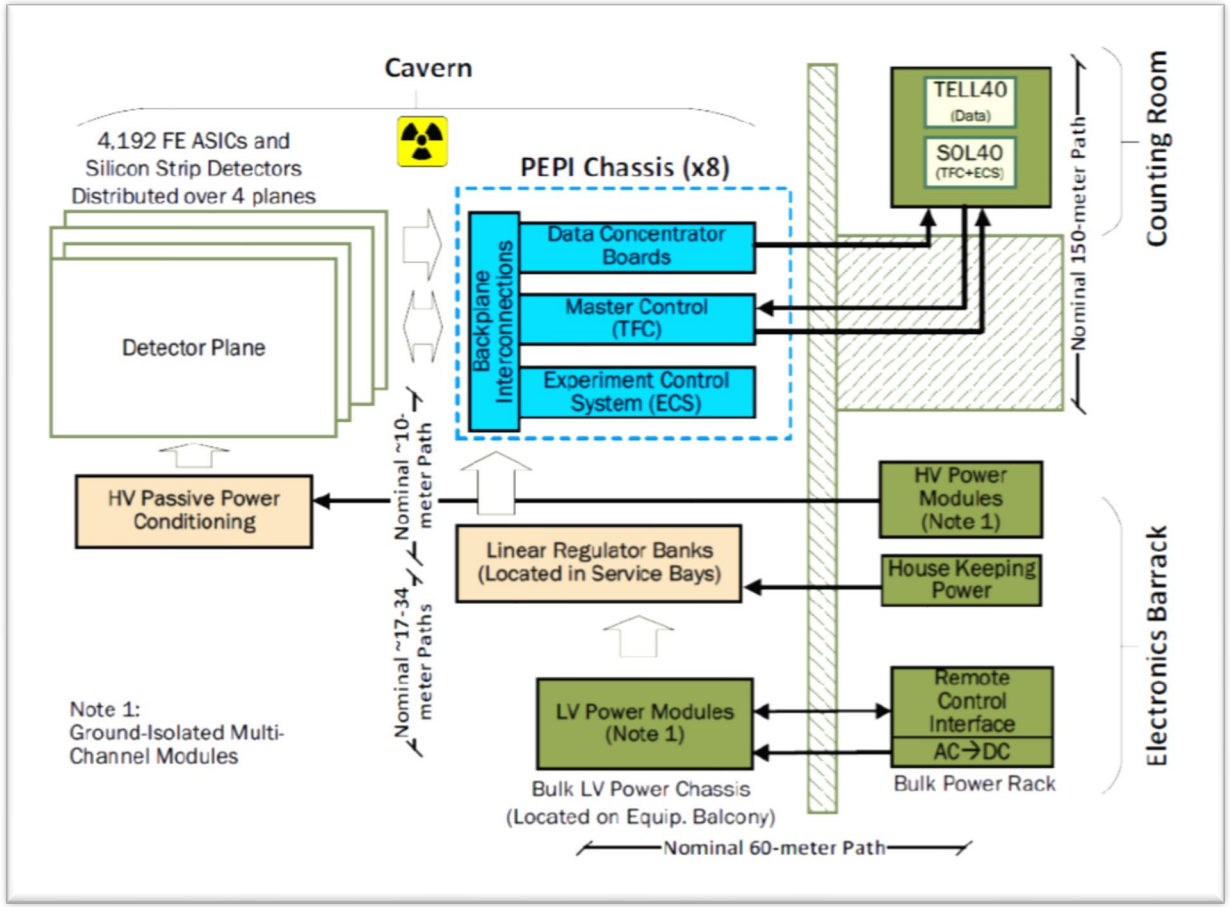
- Four detector planes composed of vertical units (staves)
  - U and V planes provide stereo information
  - staves partially overlap in X direction
- Silicon micro-strip sensors mounted on both sides of staves, partially overlapping in Y direction
  - finer strip segmentation in the central region
  - Circular cutout for beam pipe
  - Radiation hard for ~5 x 10^{14} n_{eq} cm^{-2} (~40 MRad)
- Read out at 40 MHz by FE ASICs mounted near sensors
  - analog shaping, digitization, pedestal & common-mode subtraction, ***zero-suppression***, and serialization
- Low-mass flex cable carries I/O and power
- CO_2 cooling though staves to remove heat from ASICs
  - keep sensors < -5 °C

Off-detector Electronics

- 8 Peripheral Electronics Processing Interfaces (PEPIs) adjacent to detector planes
- 4 service bays located ~10 m away from PEPIs



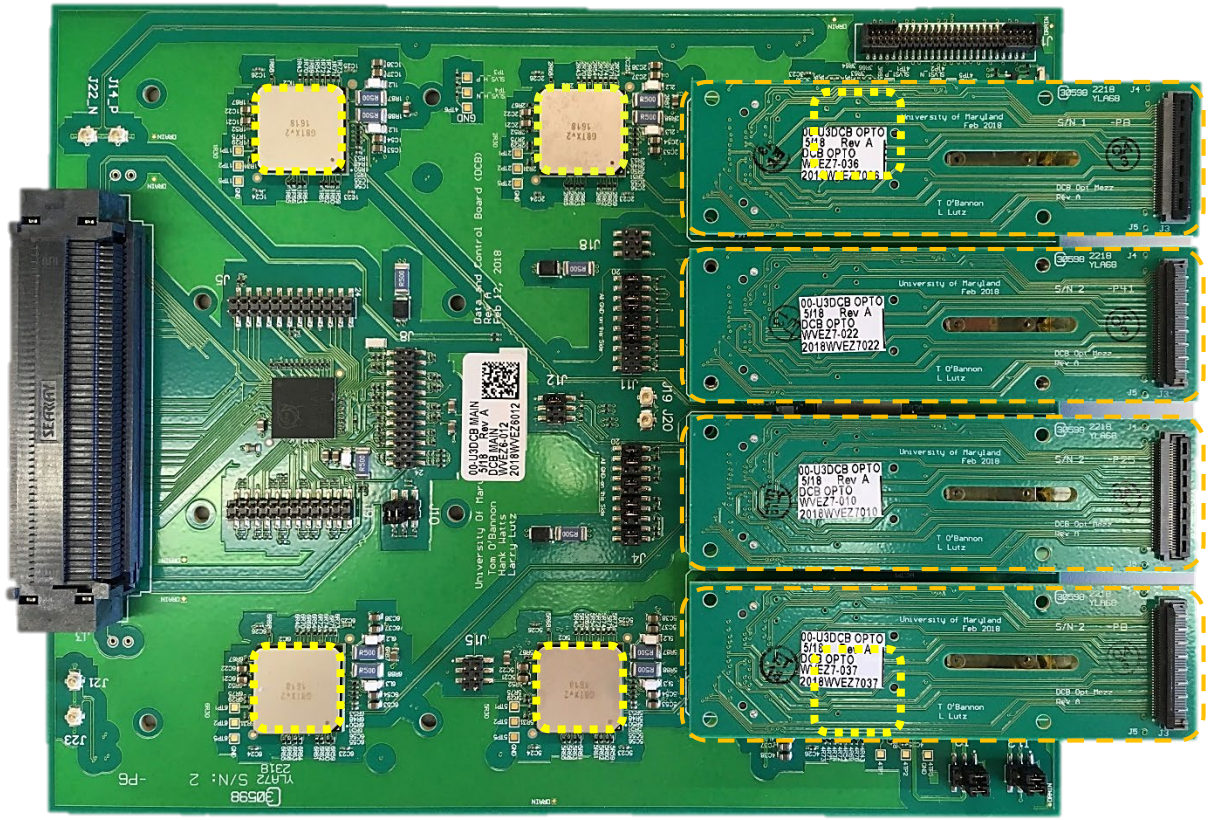
Off-detector Electronics



- Zero-suppressed digital signals transmitted through flex cables to off-detector electronics
  - *4,192 FE ASICs with 3-5 e-links per ASIC*
  - 320 Mbps for each e-link channel
- Peripheral electronics read out, repackage, and convert data into optical
  - 24-layer backplane PCBs transmit all I/O and LV power
  - Data & Control Boards (DCBs) use GBTx and VTTx/Rx ASICs to send 4.8 Gbps optical data
  - ***Total data rate ~7 Tb/s***
- Event building, timing and slow control by DAQ and FPGA boards in the counting room
- LV power regulated remotely from service bays (from ~10 m away)

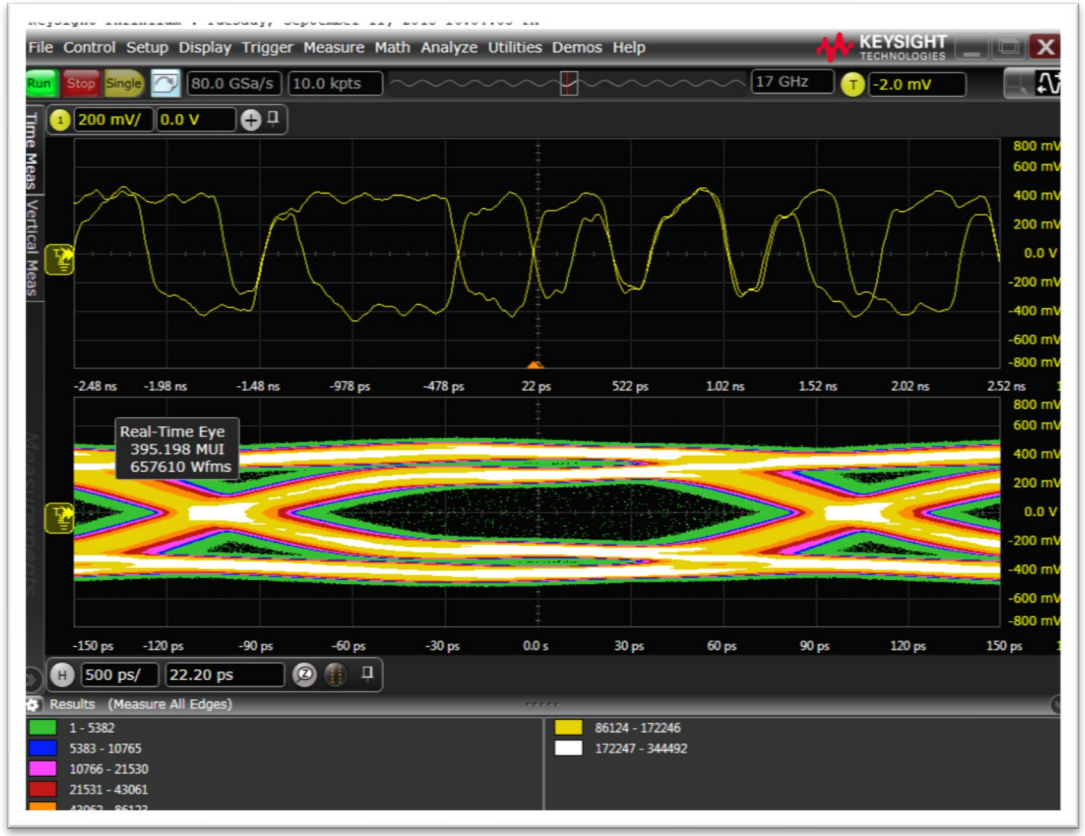
Data Transmission Fidelity

- Data & Control Boards from pre-production run are being tested
- All major functionalities validated



Data & Control Board with optical mezzanine boards

- Critical to achieve high fidelity of data transmission
- Verified up to 10^{15} bits with pseudo-random bit sequence



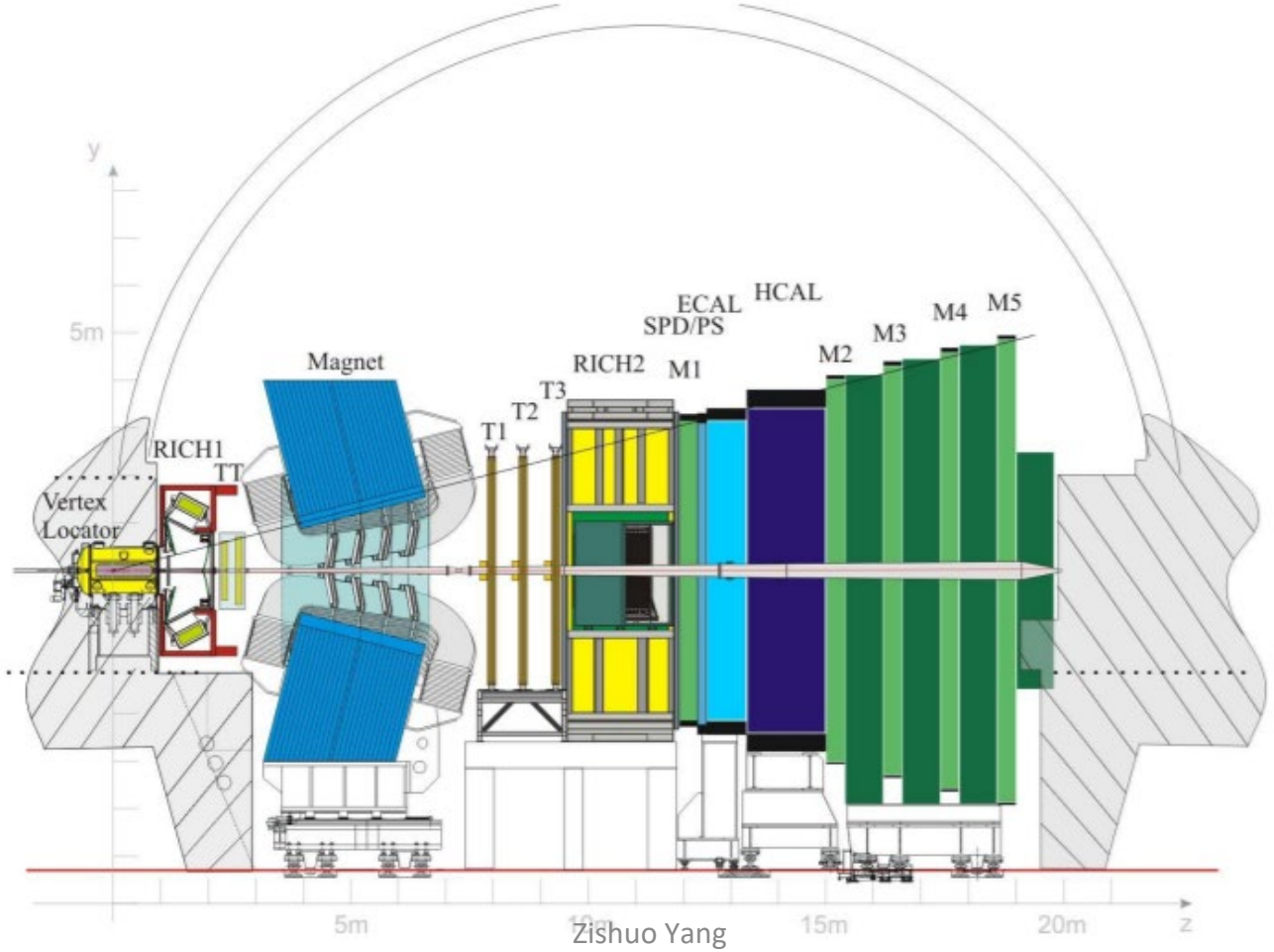
Eye diagram measurement on the DCB with 4.8 Gbps input to the VTTx

Summary

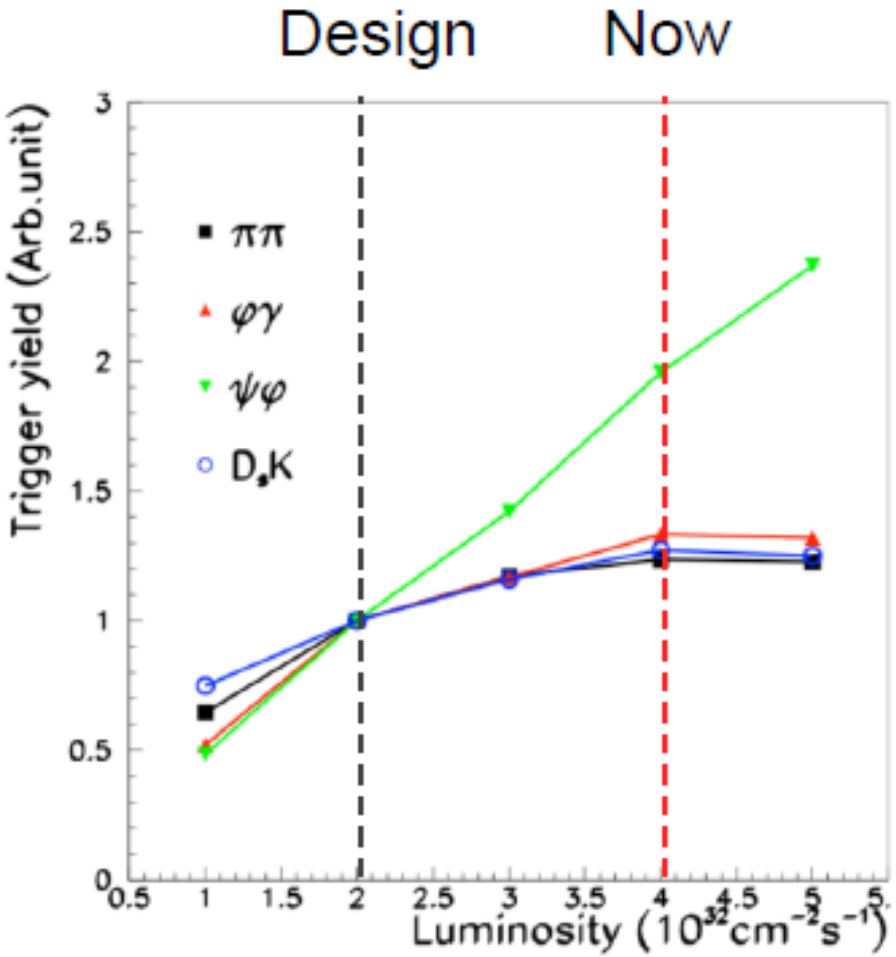
- LHCb will operate with 40 MHz readout and software-only trigger, after Phase-1 Upgrade
- The Upstream Tracker is a critical part of the upgrade
- UT off-detector electronics have been designed to read out with high speed and fidelity
- Various components of UT are in production phase
  - overall progressing well, very tight schedule
  - to be ready for LS2 installation

Backup slides

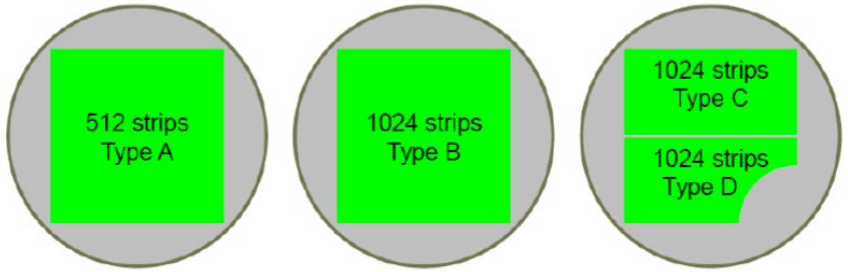
Current Detector



Limitation of current trigger



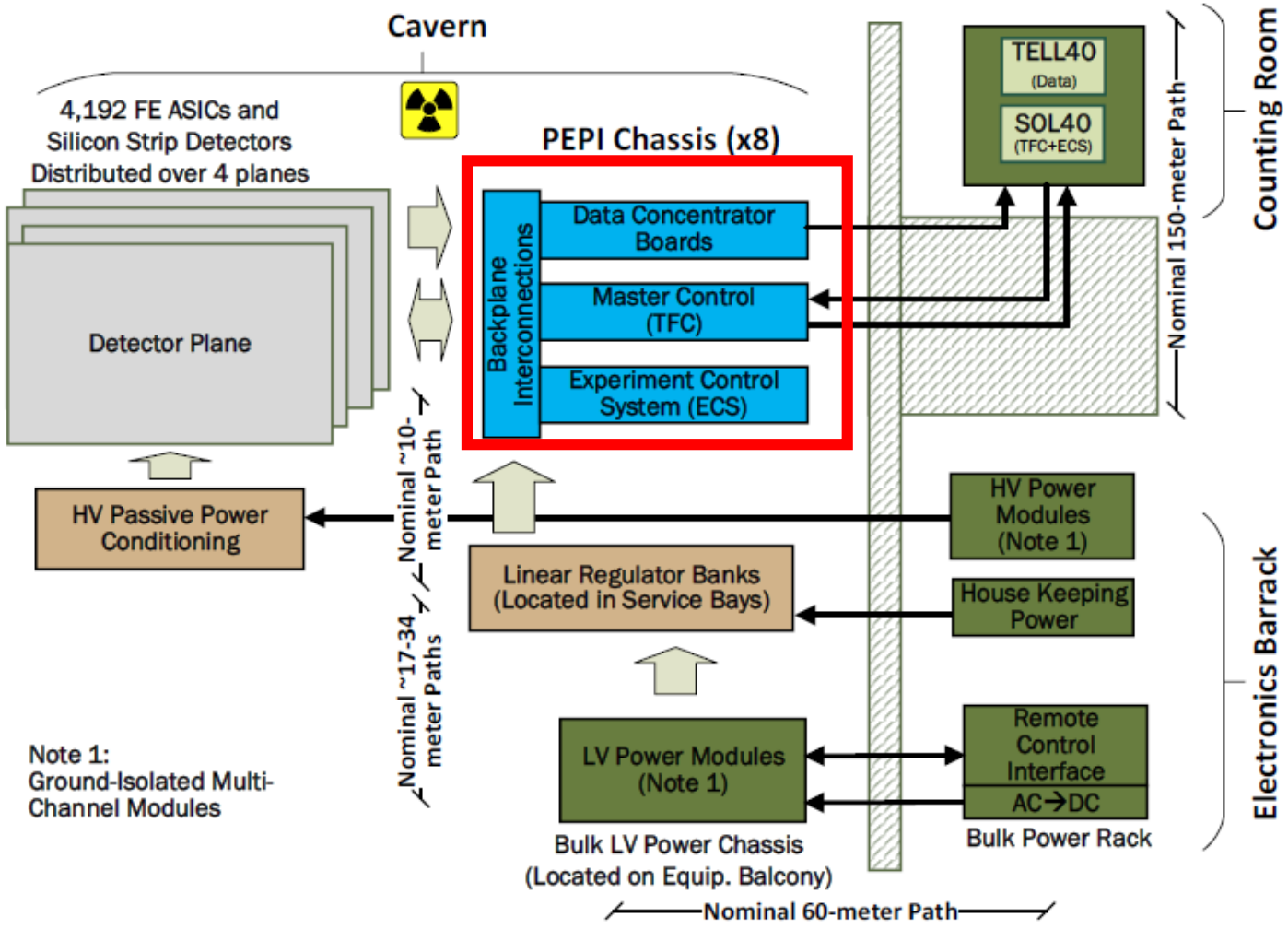
Sensor types



99.5mm by 97.5mm (and half-height) strip sensors

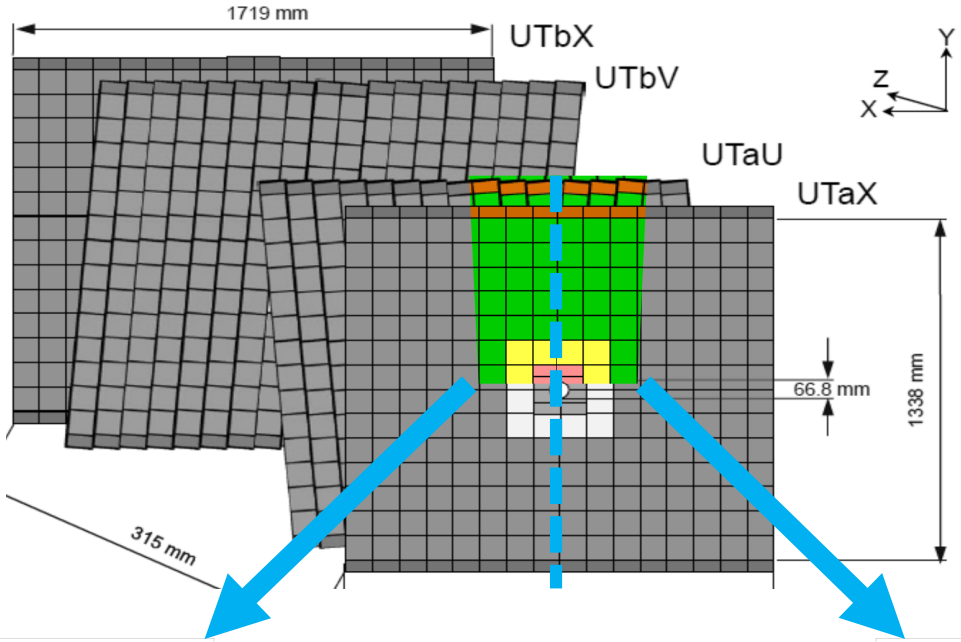
Type A: 190 µm pitch, 320 µm thickness
Type B,C,D: 95 µm pitch, 250 µm thickness
Type D: circular beam cutout to maximize acceptance

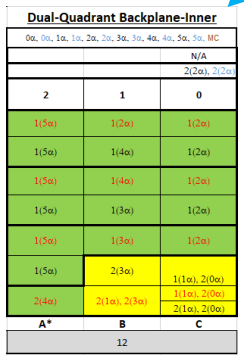
Backplane Functionality

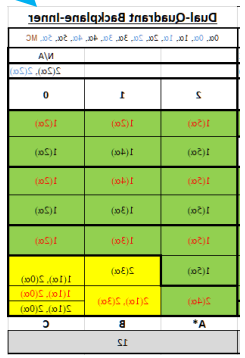


Backplane Types

- There are **2 types** of backplanes, “**true**” and “**mirrored**”, with physically different traces
  - This is due to Pigtails’ physical asymmetry between Access and Cryo sides.







PEPI Block Diagram