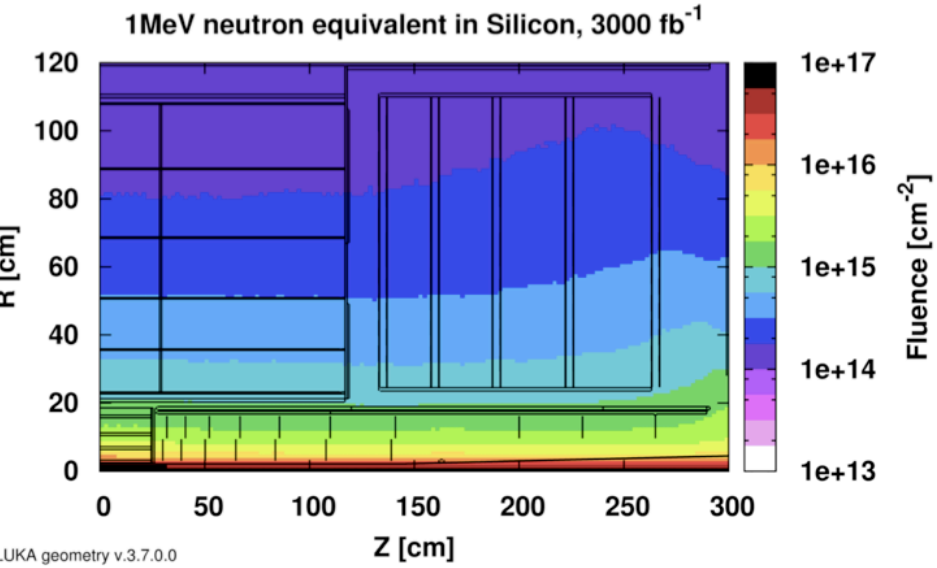
The CMS High Luminosity Outer Tracker Upgrade

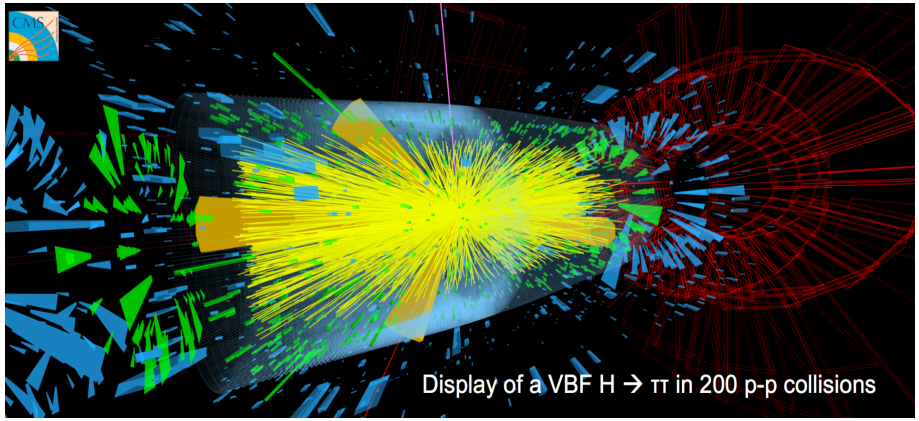
Yuri Gershtein

on behalf of CMS

Necessity to Upgrade

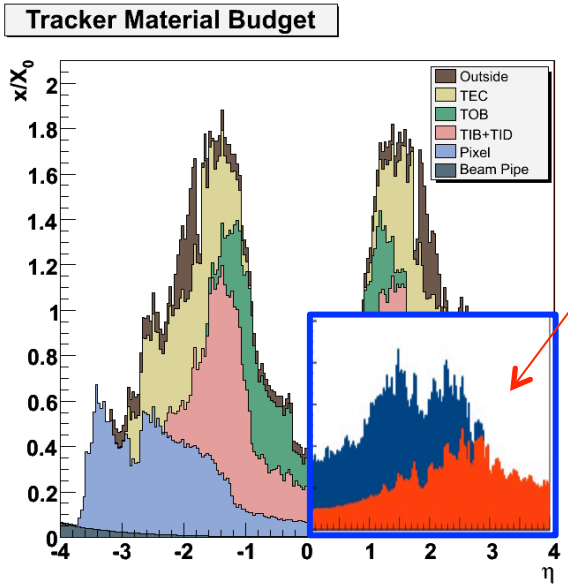
- Radiation hardness
  - Current tracker was designed to withstand ~10^{14} 1 MeV n-equivalent
  - HL-LHC program will expose the tracker to >1.5×10^{15}
- Pattern recognition in 200 pile-up condition
  - Have to cut occupancy in inner layers (12 cm strips -> 1.5 mm macro-pixels)
- L1 (40 MHz) Triggering in HL-LHC conditions
  - Muon trigger needs help (poor pT discrimination in standalone muon system)
  - Trigger processing takes longer and it's desirable to shift discrimination to HLT
    - pipeline depth: 4us -> 12.5 us
    - readout time (current limit is 100kHz, need ~750kHz)





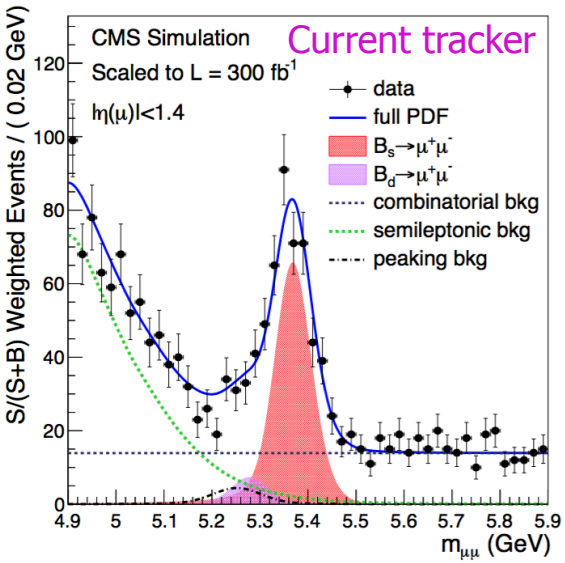
Low mass and better spatial measurements

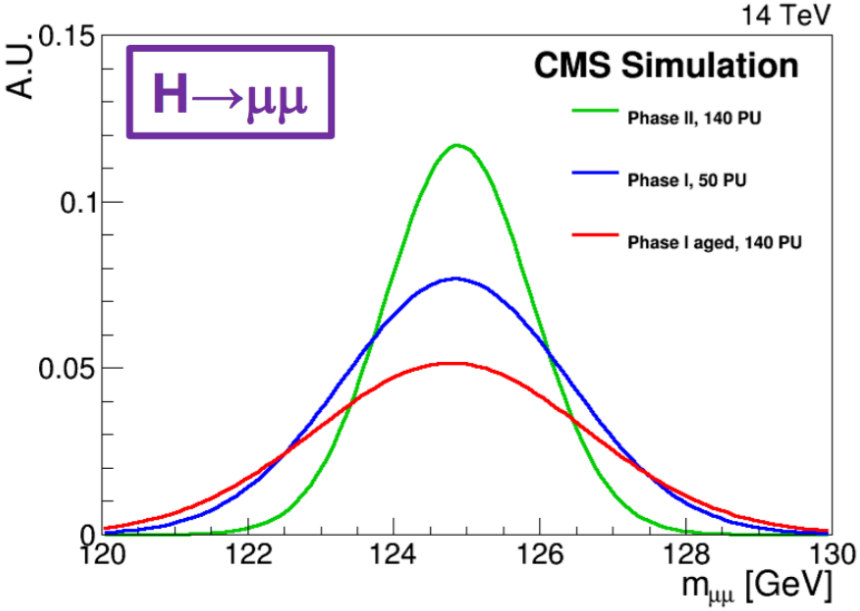
Current tracker

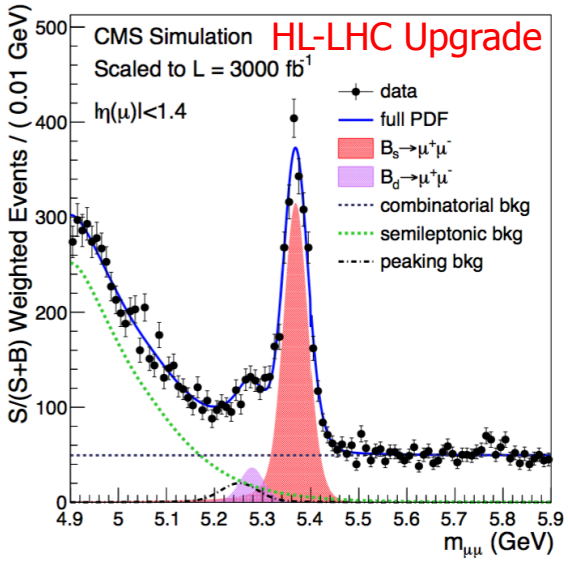


HL-LHC Upgrade

$B_S \rightarrow \mu\mu$

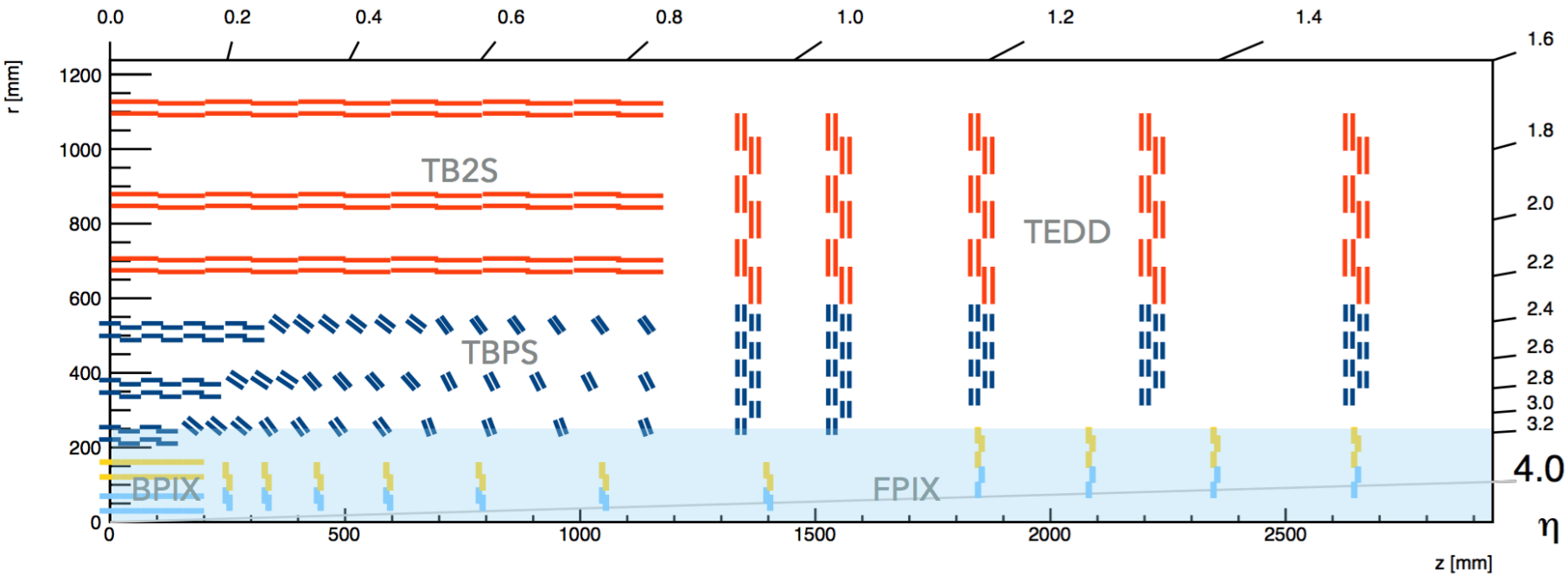






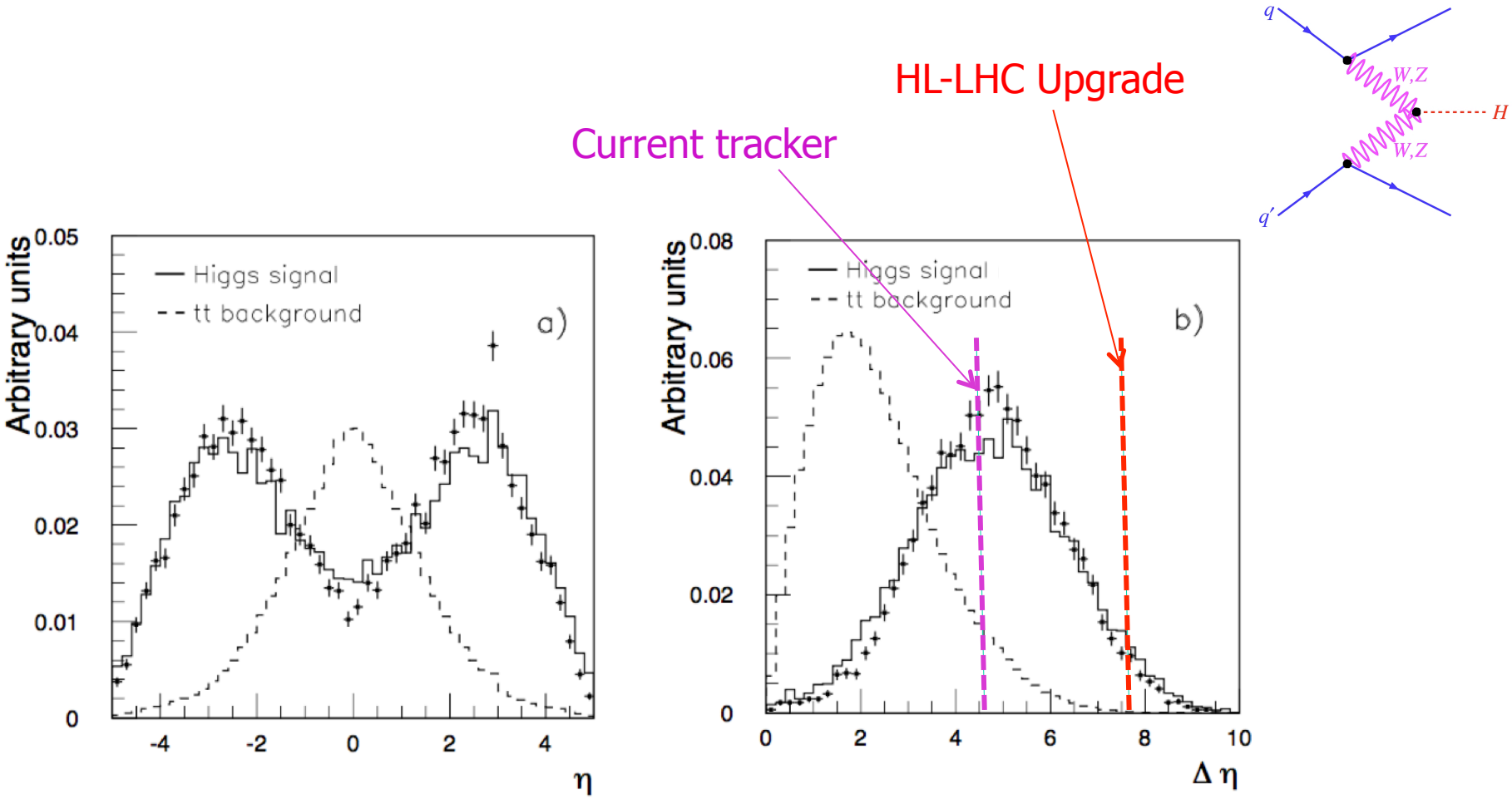
Lighter, Faster, Cooler

- Make the new tracker better then the current one



- Pixels: 4 barrel layers plus 2x11 disks
  - New layout / mechanics for better material distribution, and ability to install / remove the detector with beam pipe in place
  - Coverage extended to $\eta \sim 4.0$ ($\Delta\eta$ between Higgs VFB jets ~5)

Lighter, Faster, Cooler



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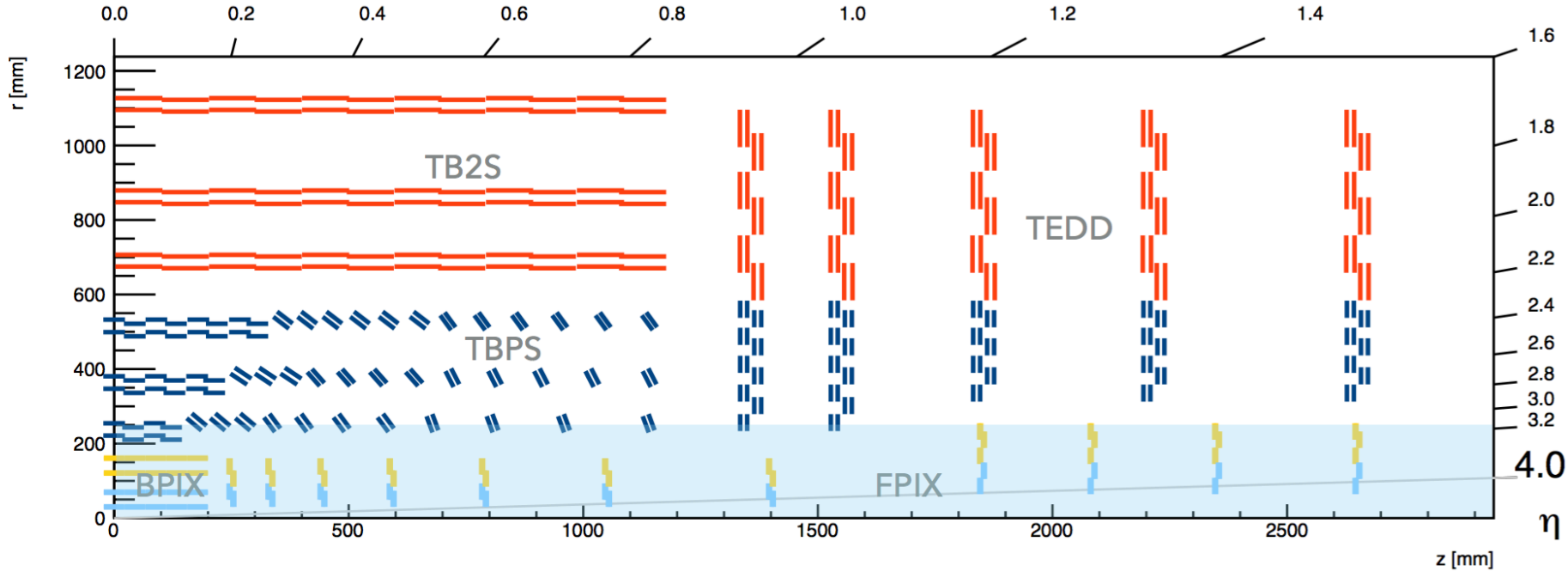
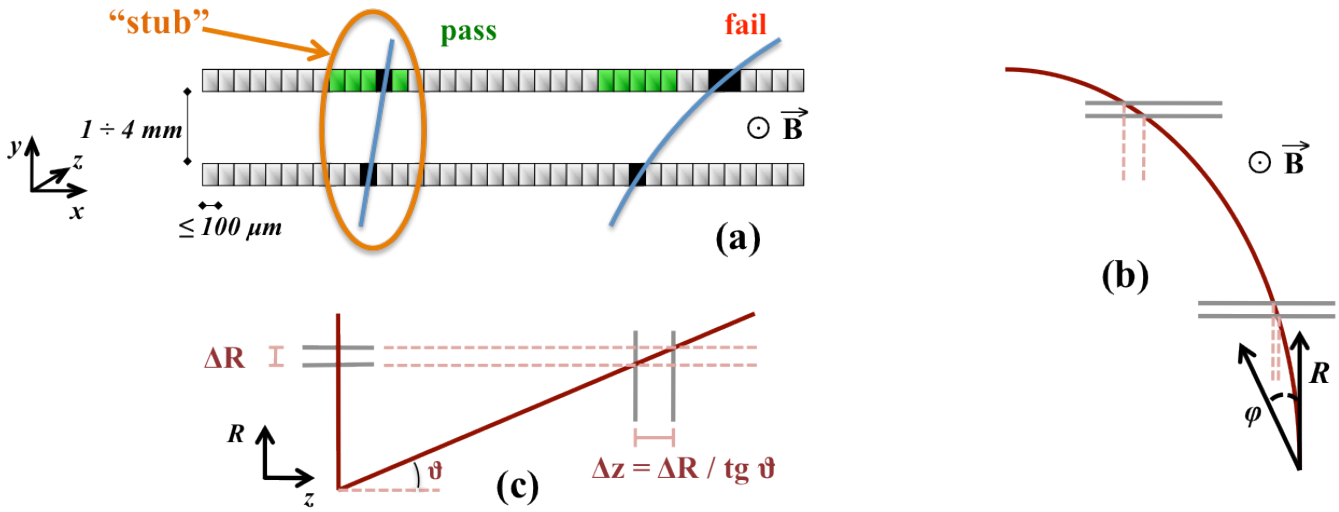


- Strips: 6 barrel layers plus 2x5 disks, n-in-p sensors with p-stop strip isolation
  - R<60 cm: *PS modules:* macro-pixels (1.5mm) and short strips (2.5 cm)
    - Partially tilted
  - R>60 cm: *SS modules:* strips (5 cm)
- All of the tracker is digital – no amplitude information
  - *Except for short strips there are two thresholds, so have some dE/dx*

Stacked Sensors (Pt modules)

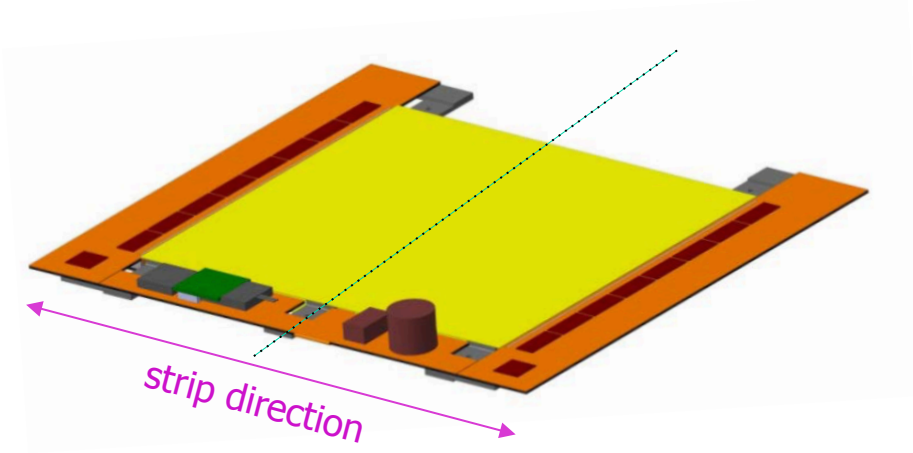
- Huge number of hits drives the readout time – not feasible at 40 MHz even for binary readout
- Solution: stack of two sensors that both run strips along the beam
  - The pair of hits (stub) measures pT of the track that left them
  - The electronics that measures that pT lives on the module – a factor of order 100 in the occupancy, sufficient to make readout of the high pT hits possible
- Sensor separation is optimized based on position
- At high rapidity, large Z separation between hits for the same R separation



Two Types of Modules

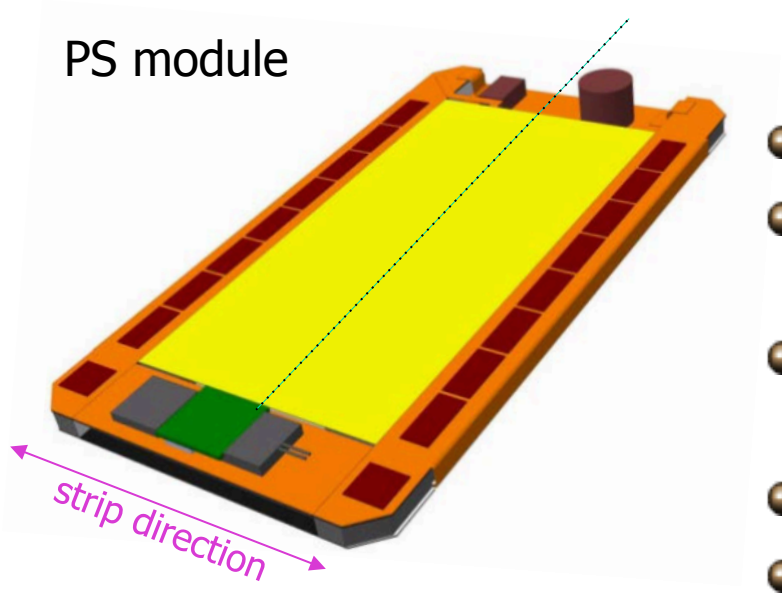
Both module types have two independent FE: tracks crossing from one half to the other do not form a stub

2S module



- ~10 x 10 cm
- Two identical sensors
- 90 microns x 5 cm strips, AC coupled, polysilicon bias resistors
- Sensor separations of 1.8 and 4mm
- ~5W x 8224 modules

PS module



- ~10 x 5 cm
- PS-s:100 microns x 2.5 cm strips, AC coupled, polysilicon bias resistors
- PS-p:100 microns x 1.5mm pixels, DC coupled, punch through bias
- Sensor separations of 1.6, 2.6 and 4 mm
- ~8W x 5332 modules

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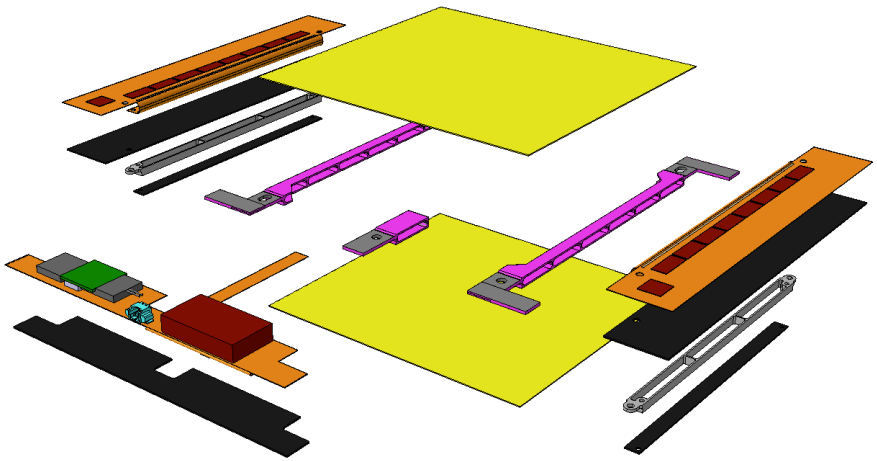

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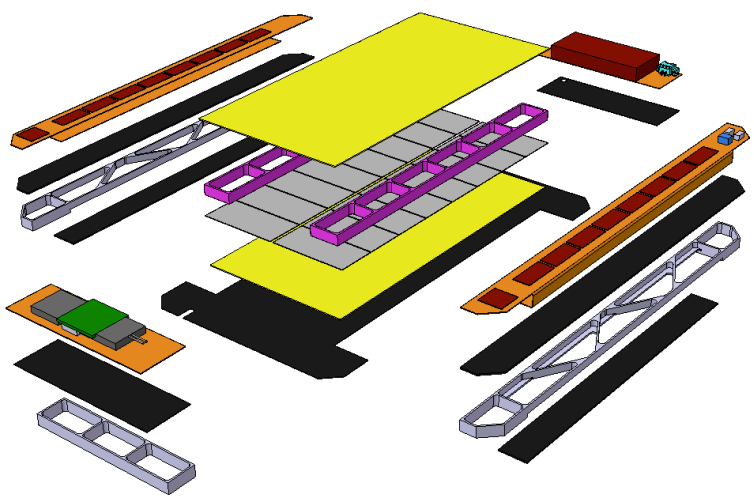

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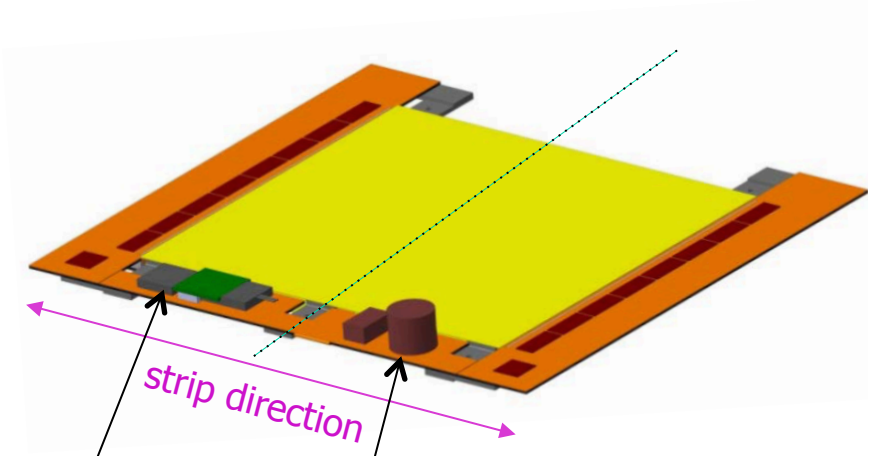
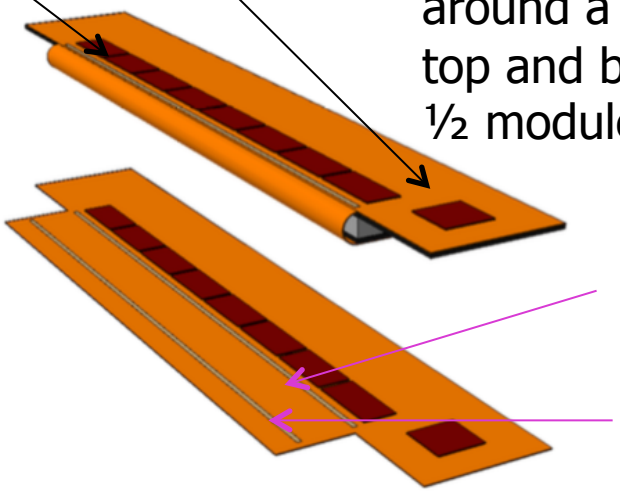


CBC

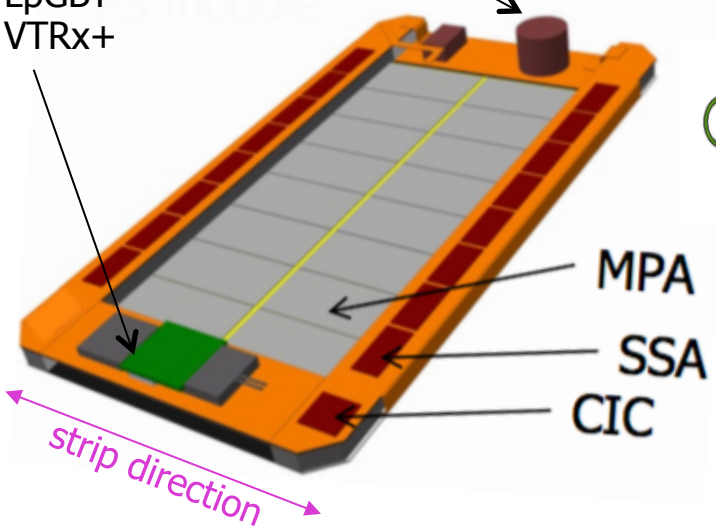
CIC

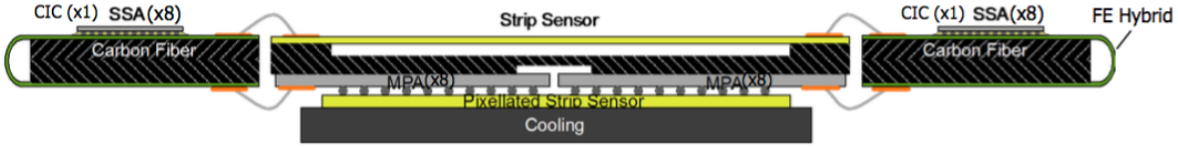
Front End Hybrid wraps around a stiffener and gets top and bottom strips from ½ module



DC-DC

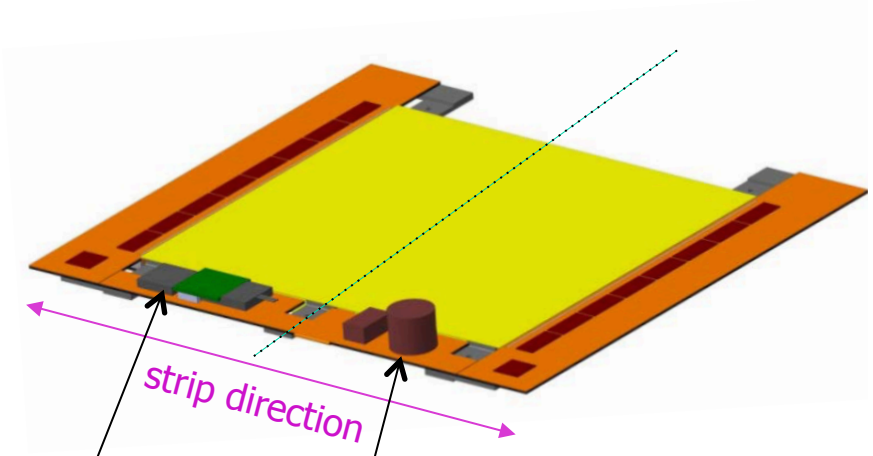
LpGBT
VTRx+





Two Types of Modules

2S module



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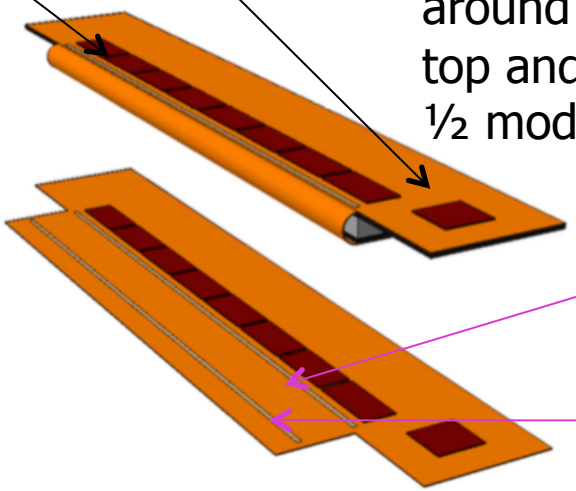
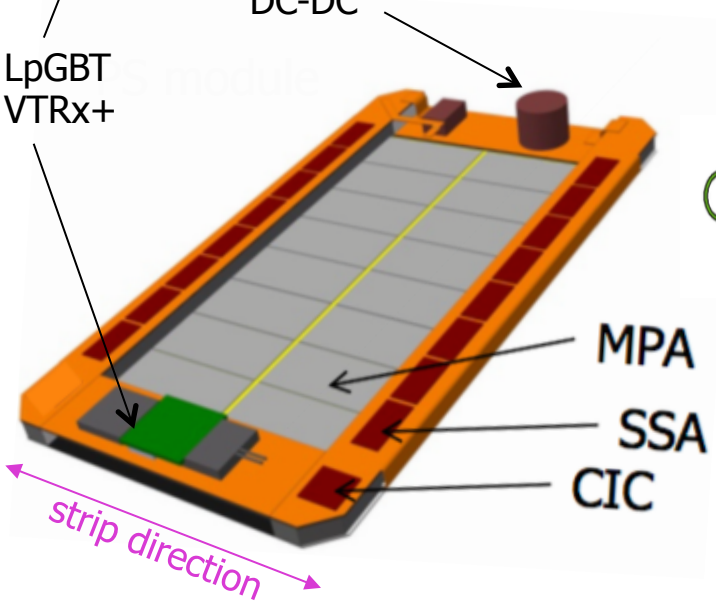


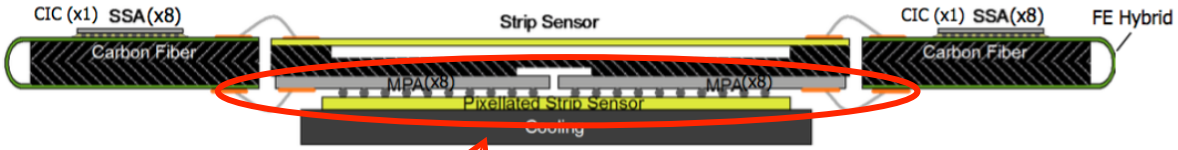
Top sensor wire bond pads

Bottom sensor wire bond pads

DC-DC

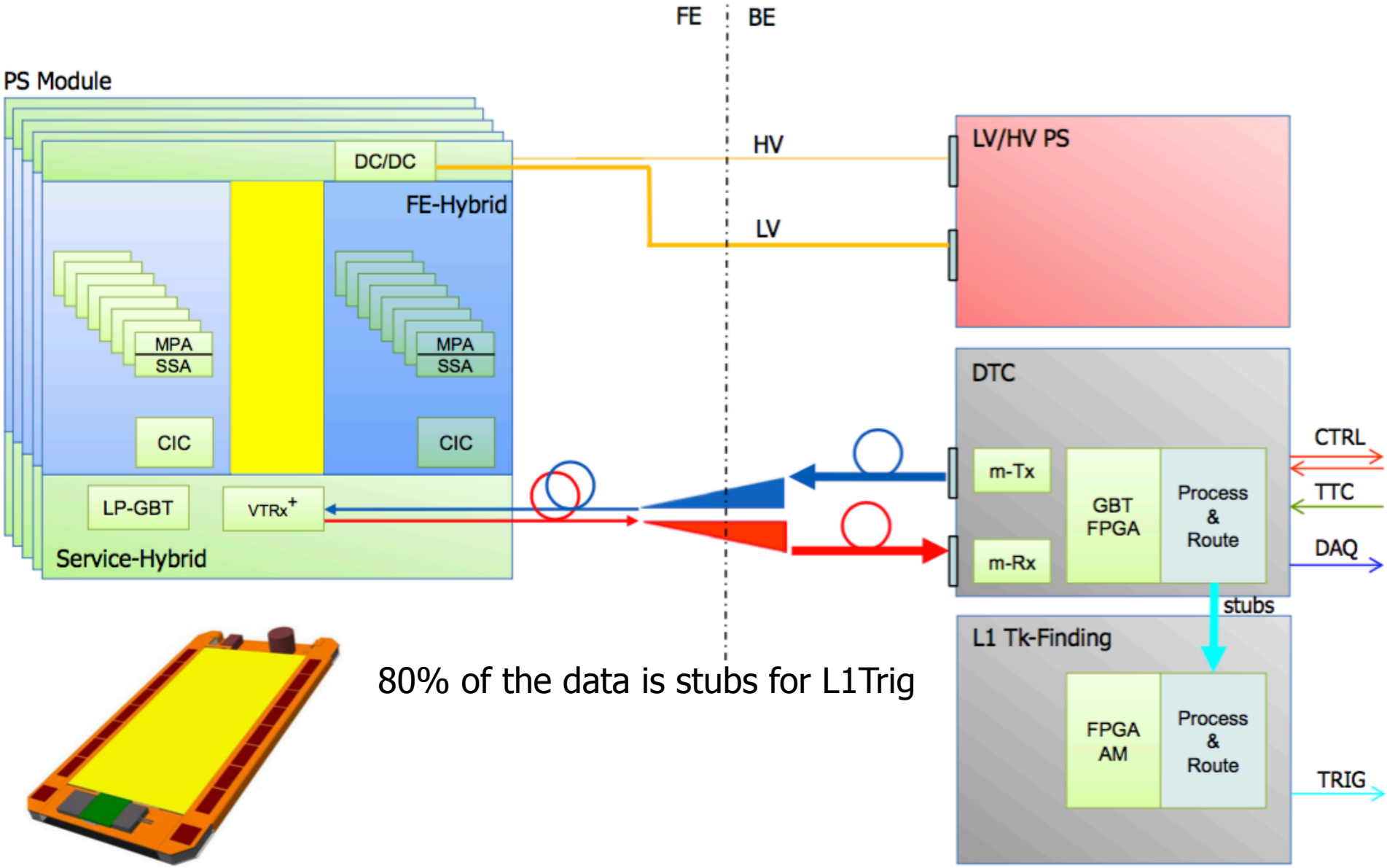
LpGBT
VTRx+





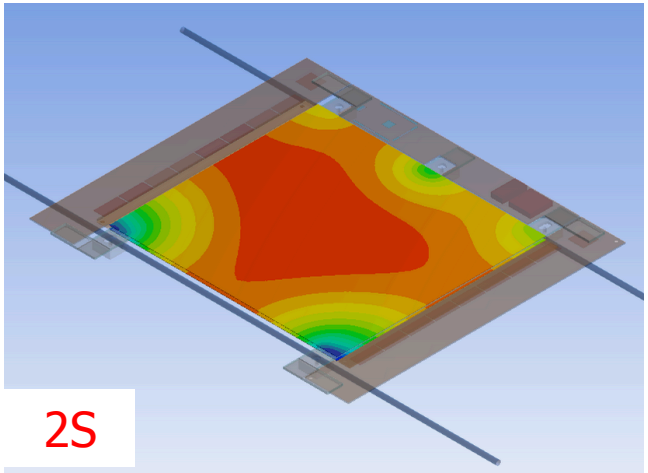
Macro Pixel Sub-Assembly (MAPSA)
16 MPA chips bump-bonded to a single sensor

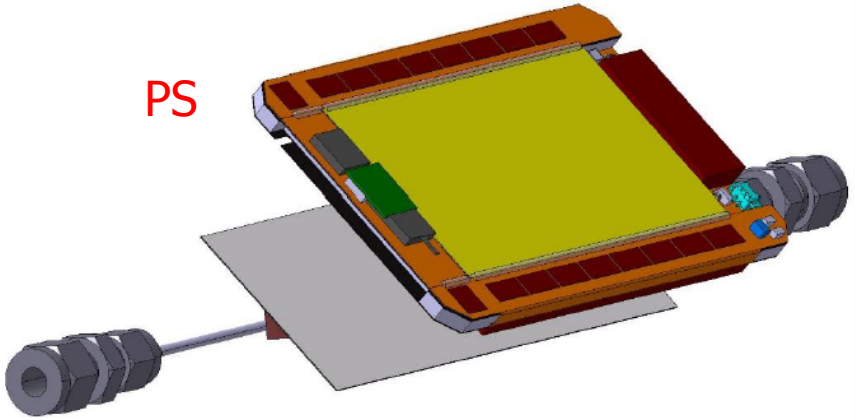
Electronics

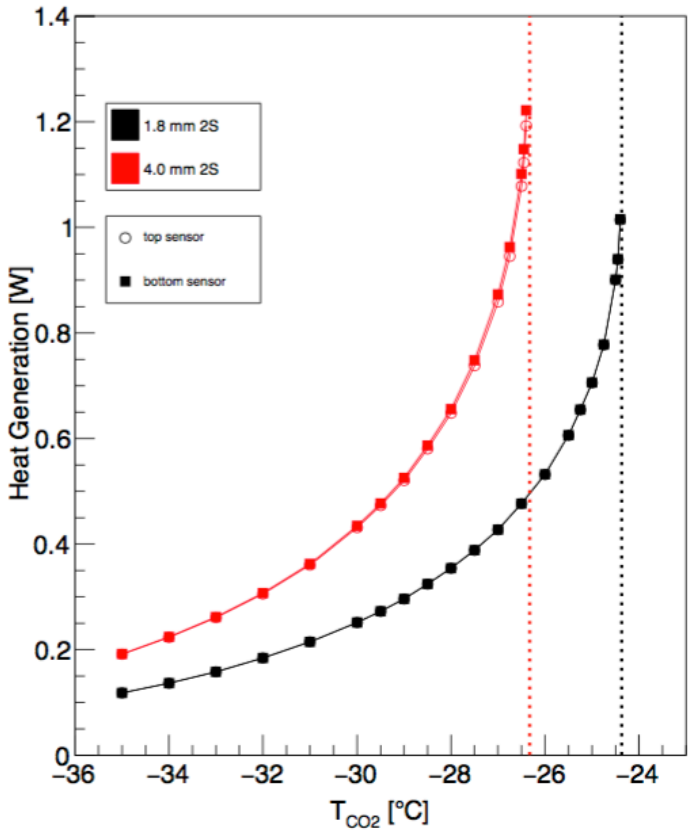


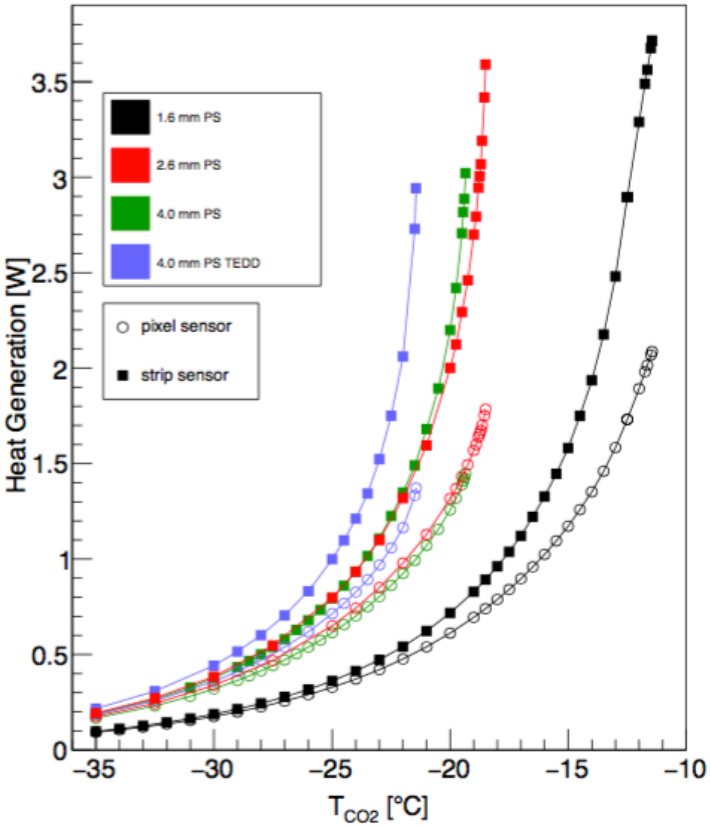
80% of the data is stubs for L1Trig

2-phase CO_2 cooling



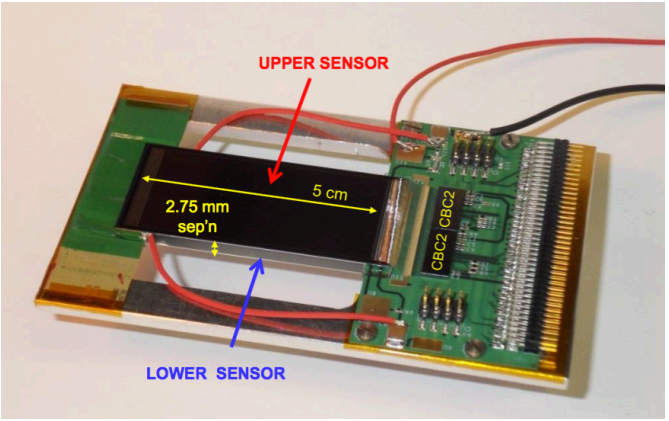


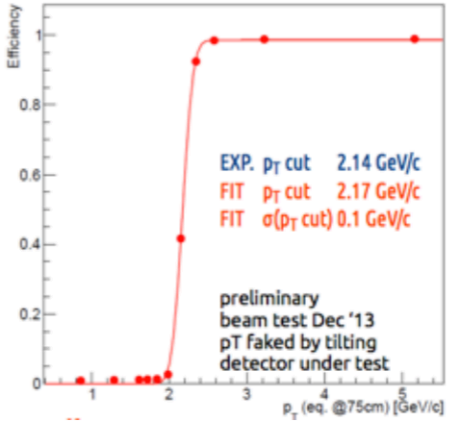




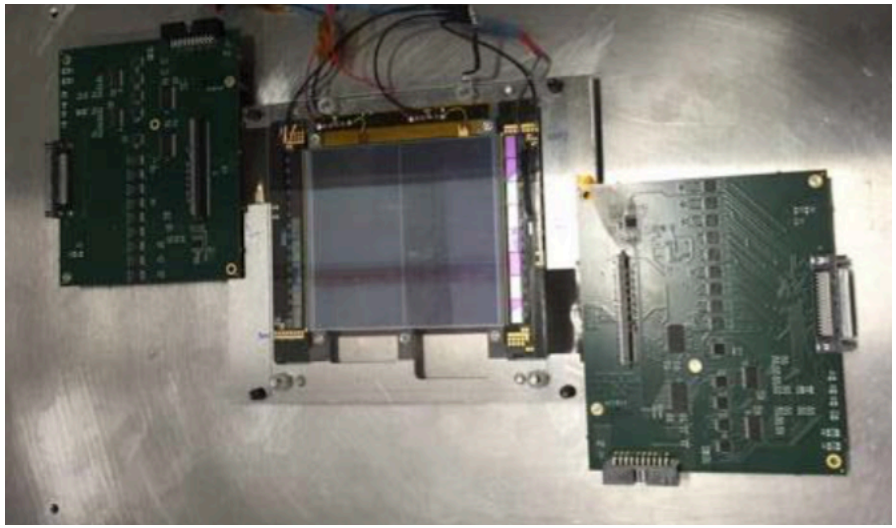
Prototype Tests 2S

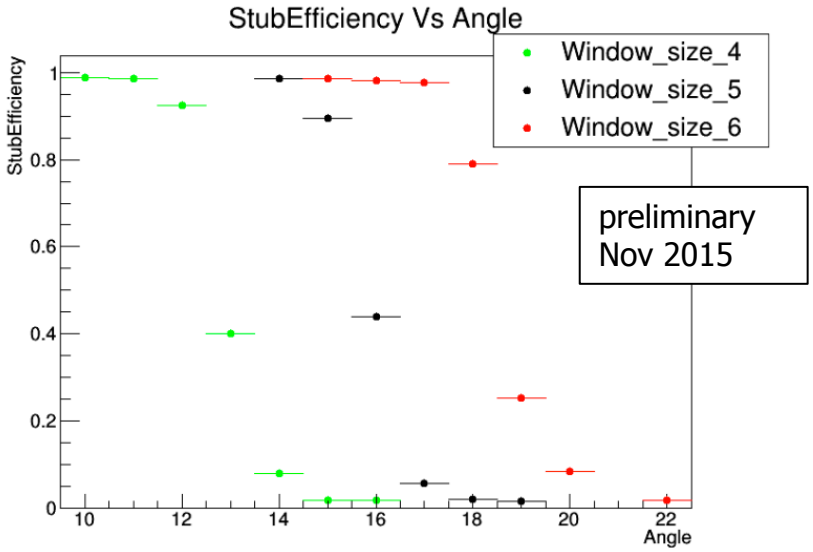
- The stub-forming functionality has been demonstrated in 2013 tests of a mini-module and a CBC prototype
  - Emulate the pT bending by tilting the module





- Full size module is now under study

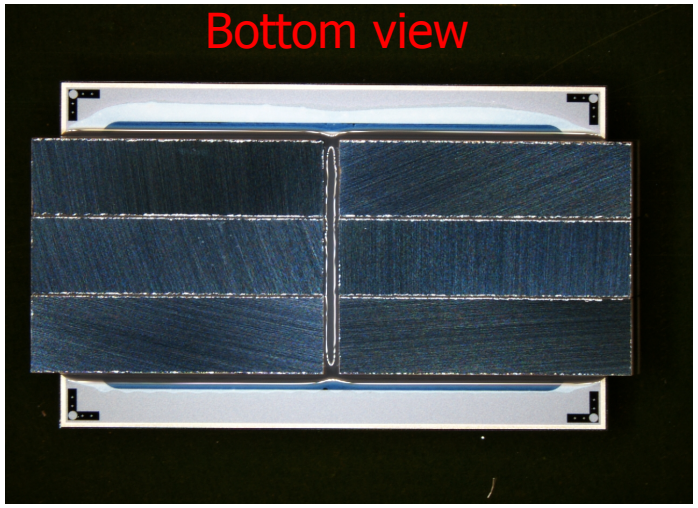


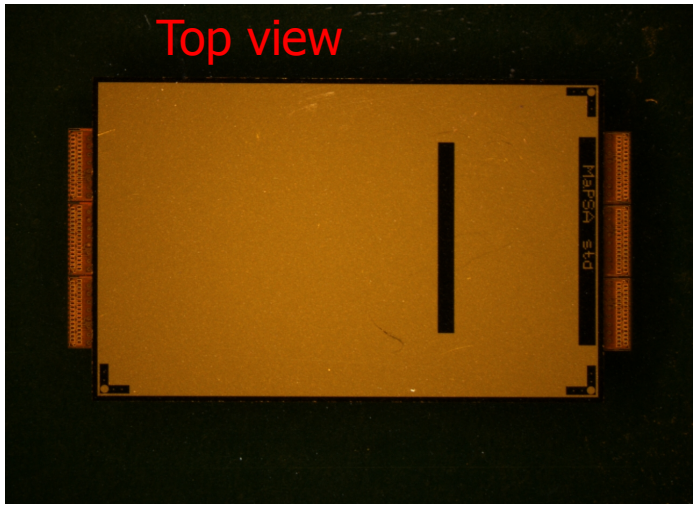


PS Module prototyping

- Prototype MPAlight chip ("final" MPA analog circuits)
  - Same geometry, only 48x3 pixels
  - clustering and stub formation logic
  - Bump-bonds and bond pads on the same surface
- Prototype sensor to fit 6 MPAlight chips: MaPSALight

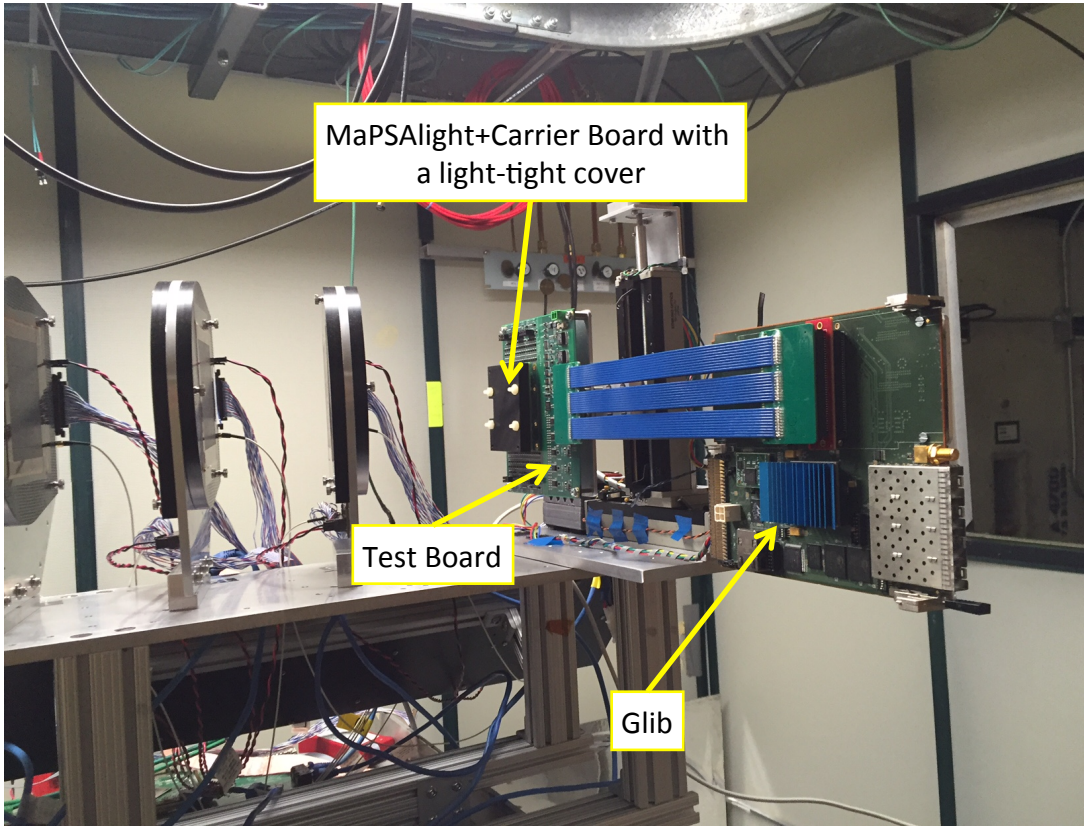
2 X 3 MPA-Light chips

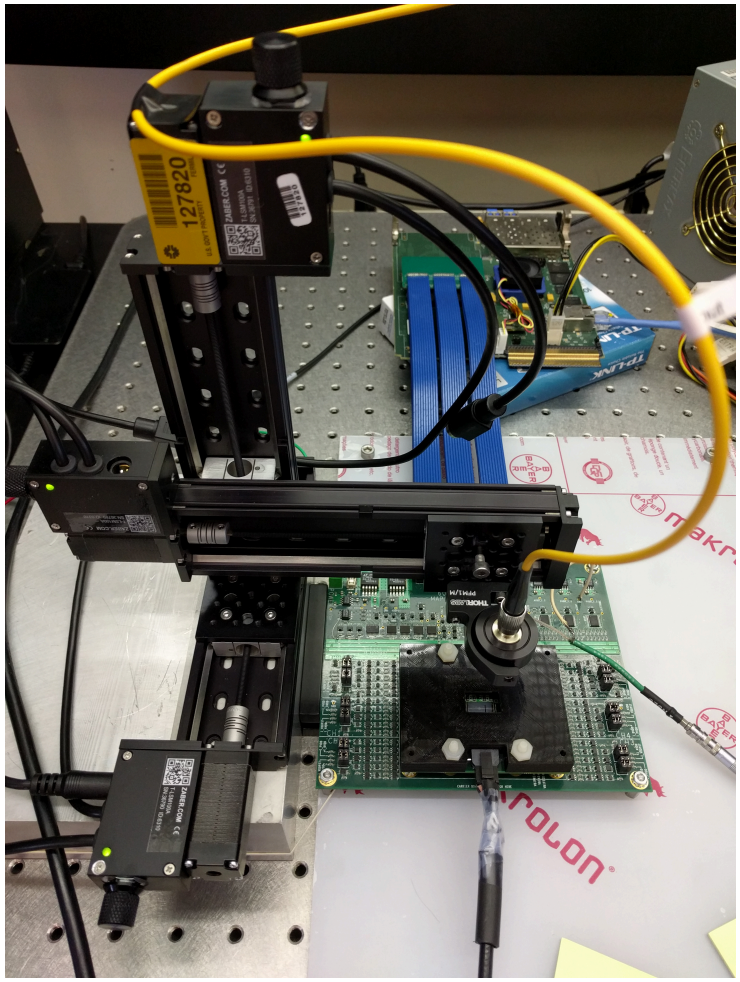




PS Module prototyping

- Validating bump-bonding vendors
- Beam / bench tests
  - Confirmed simulations of time walk, measure dispersion of pedestal values, etc





Summary and Outlook

- HL-LHC requires complete replacement of the tracker
  - Will not survive 3/ab
  - Poor pattern recognition in 200 pile-up
  - no single muon trigger of any pT
- New tracker design addresses all these issues:
  - Much lower mass
  - Increased granularity and resolution
  - Track reconstruction @L1 (@40 MHz)

200 m^2, 218 M channels

- Design is in good shape
  - Many challenges and deadlines ahead
- TDR is in preparation
  - Yet to make several important decisions, especially on the Back End, including L1 Track Trigger technology