The CMS Phase-II Tracker Upgrade

Steven Lowette
Vrije Universiteit Brussel

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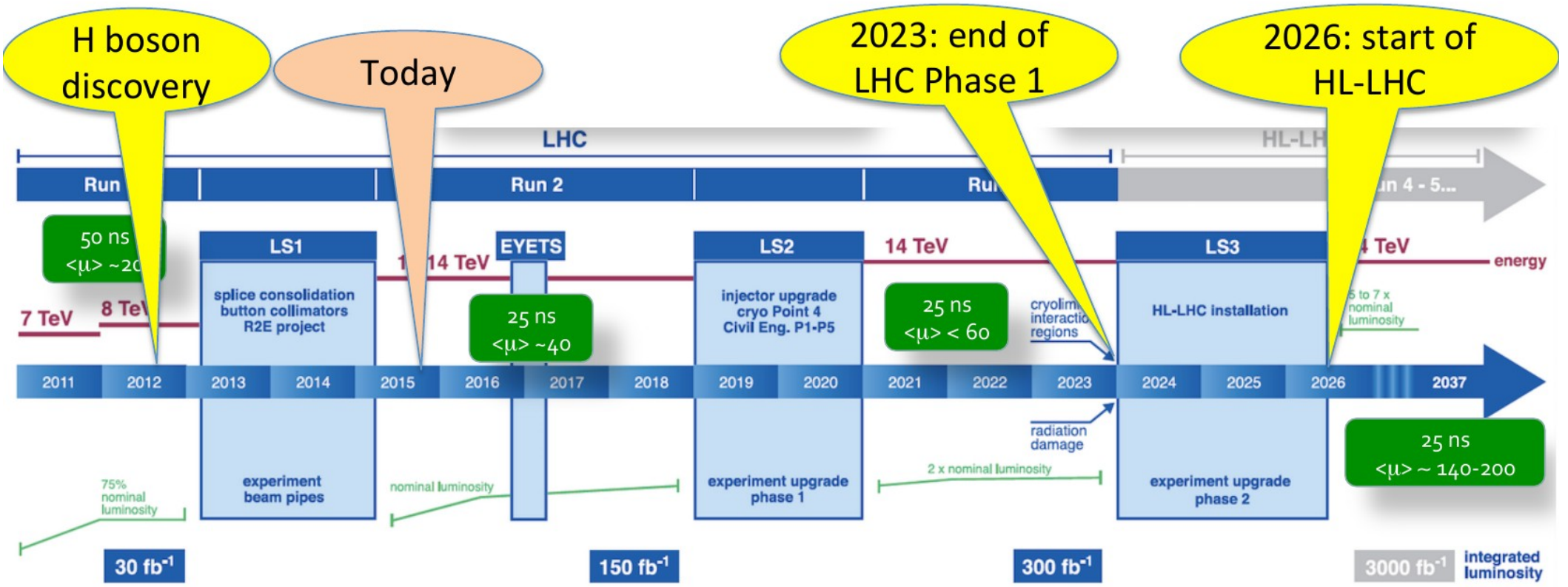
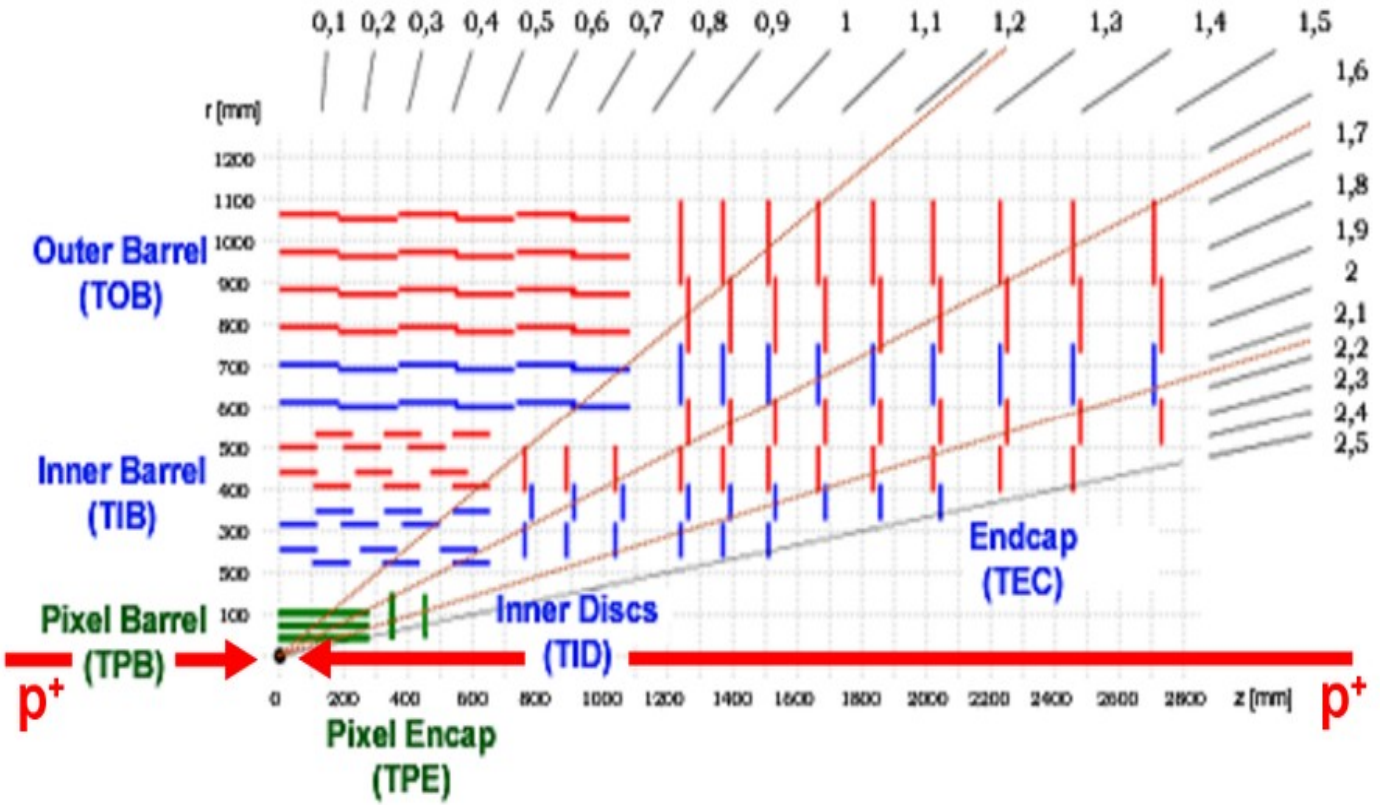
The LHC Timeline



- the High-luminosity LHC (HL-LHC) plans to collect 10 times more luminosity at 5-7 times higher beam "intensity" as the LHC
- the HL-LHC was approved by the CERN council in June 2014; it is highest on the priorities of the European Strategy for Particle Physics

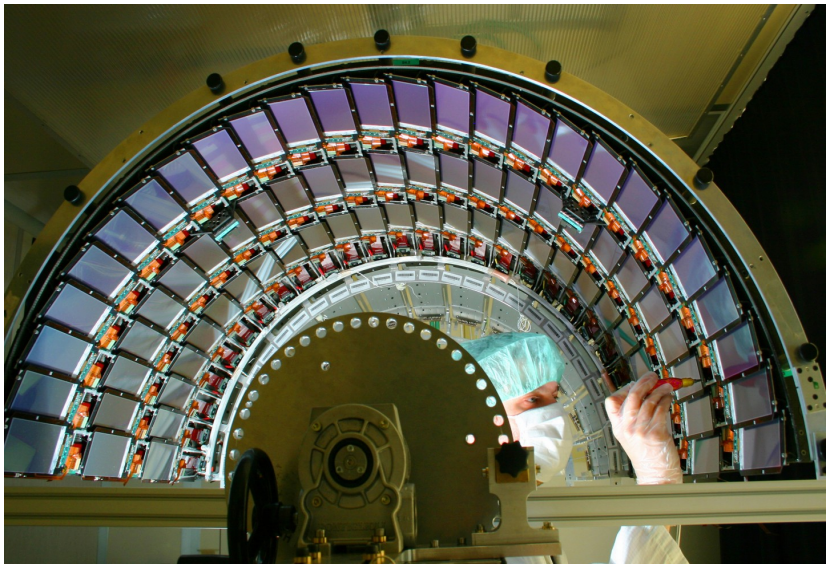
Current Tracker Situation

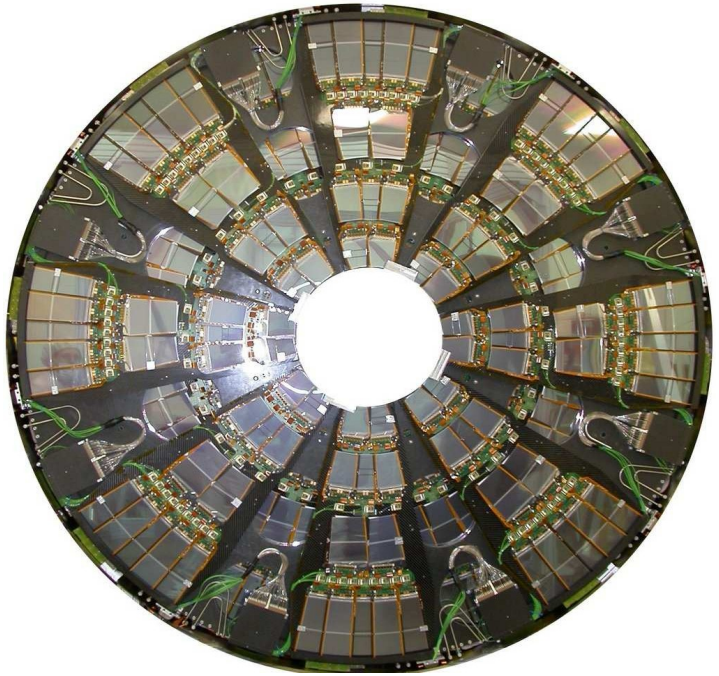
- current CMS tracker



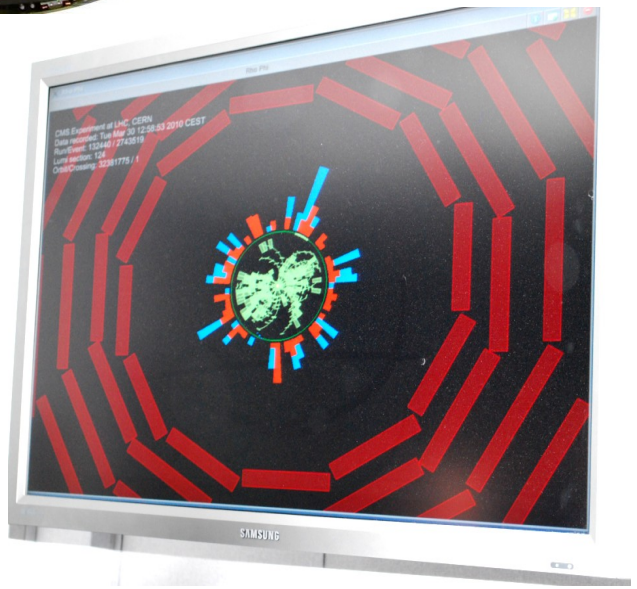
- harsh environment for pixel detector
  - to be replaced first time 2016-2017
- strip detector to go untouched until 2023

Current Tracker Situation



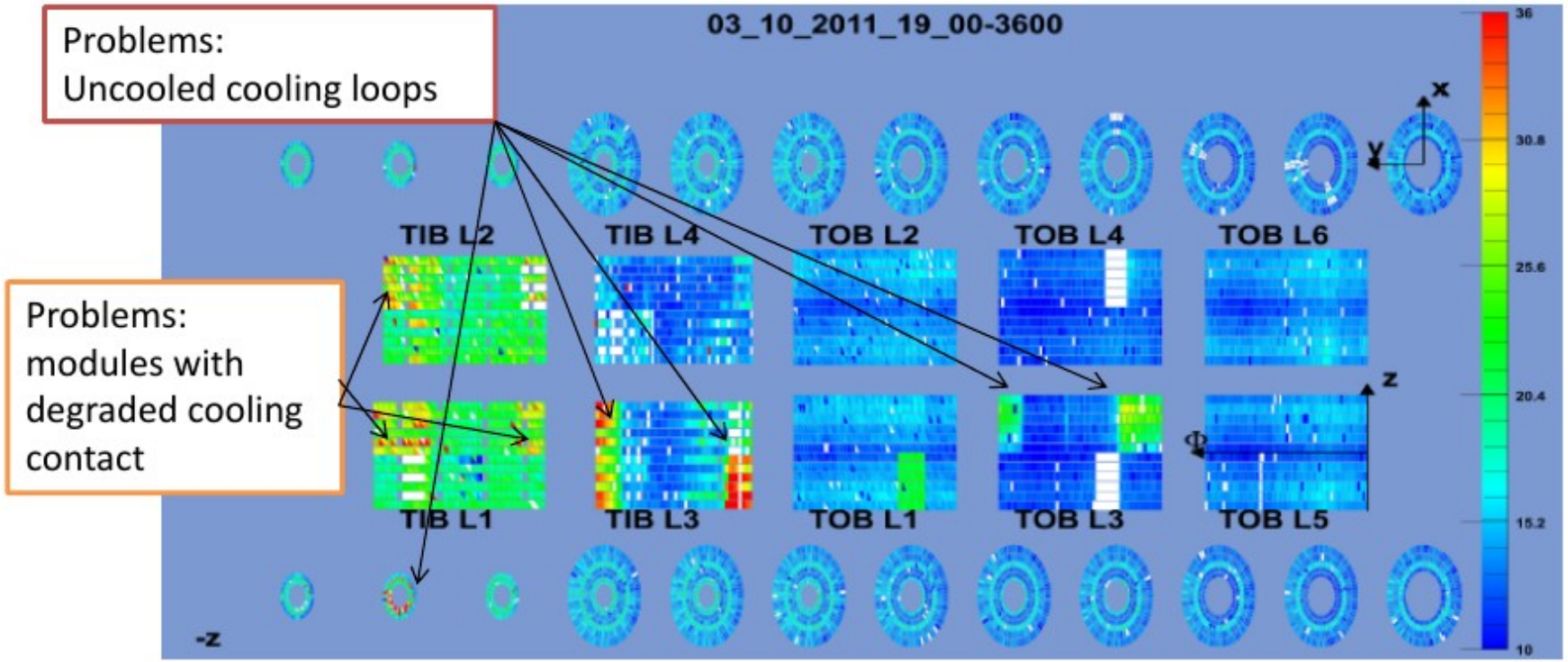


- the CMS tracker is a remarkable success story with an excellent performance in data taking
- strong Belgian contribution in construction, commissioning, and operation



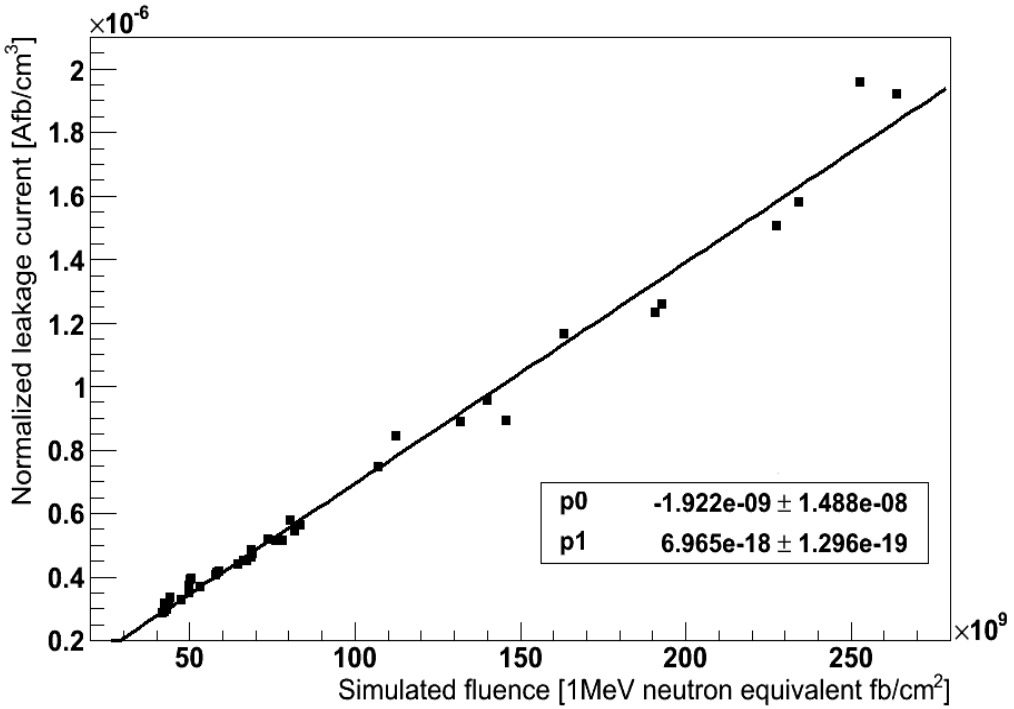
Current Tracker Longevity

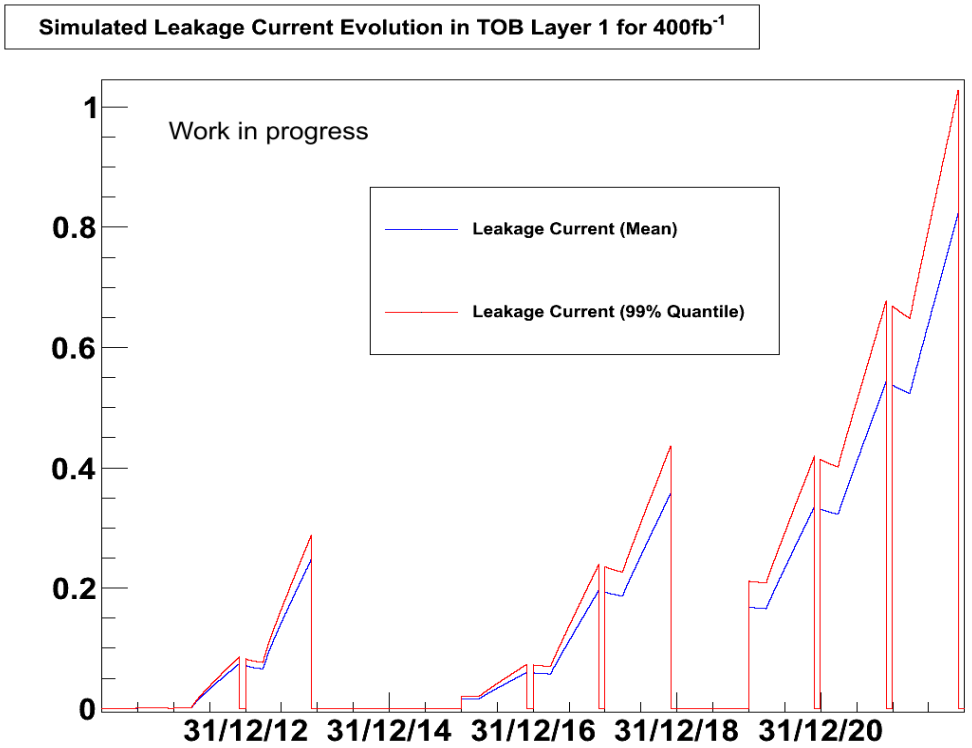
- CMS strip tracker was designed to withstand 500/fb
- operating temperature crucial parameter for longevity
  - every 7C doubles/halves the leakage current
  - also important for depletion voltage, noise, etc
  - current operating temperature coolant -15C



Current Tracker Longevity

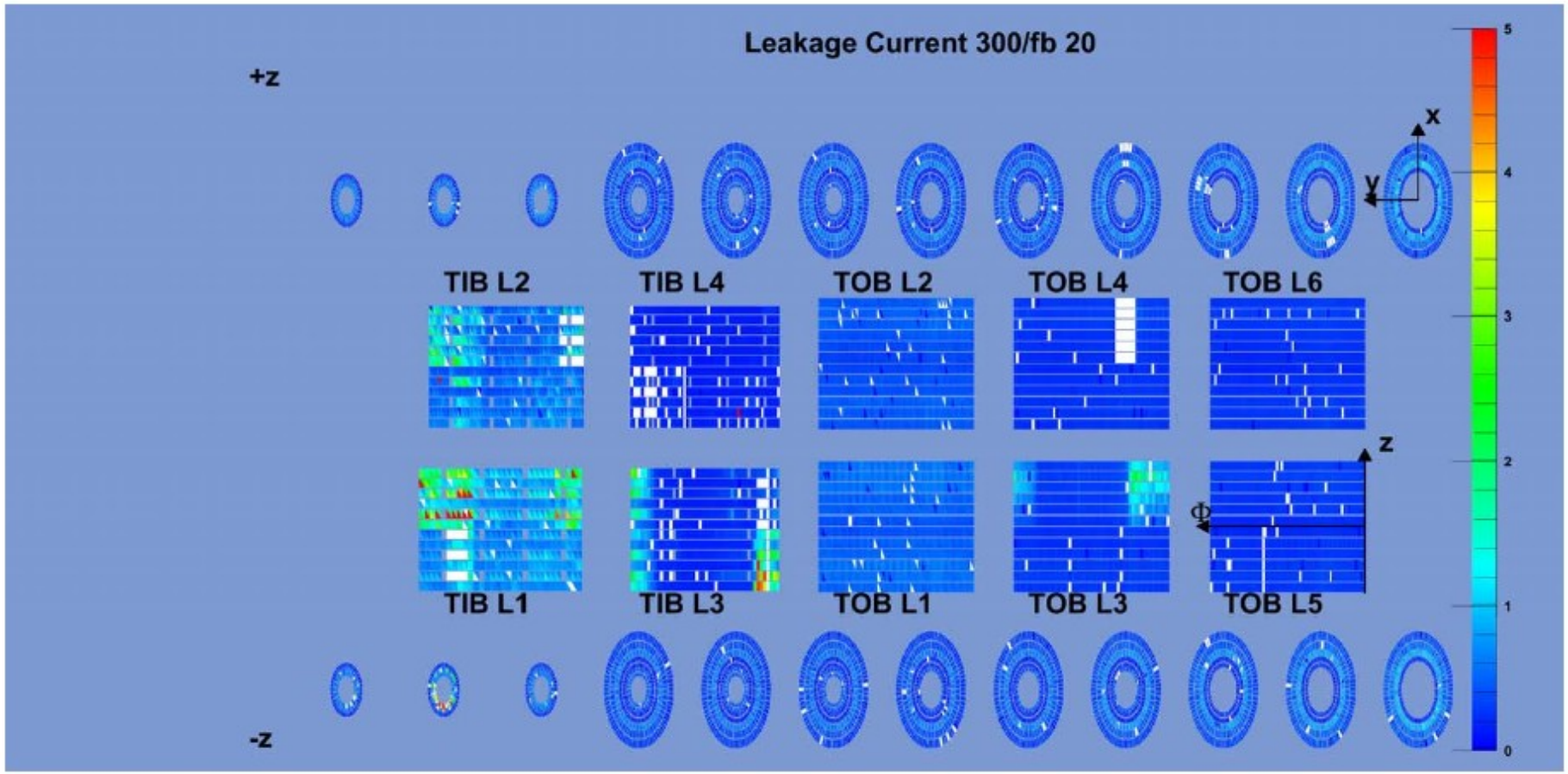
- example crucial parameter: leakage current
  - linearly proportional to fluence
  - some mitigation from annealing
  - simulations based on measurements





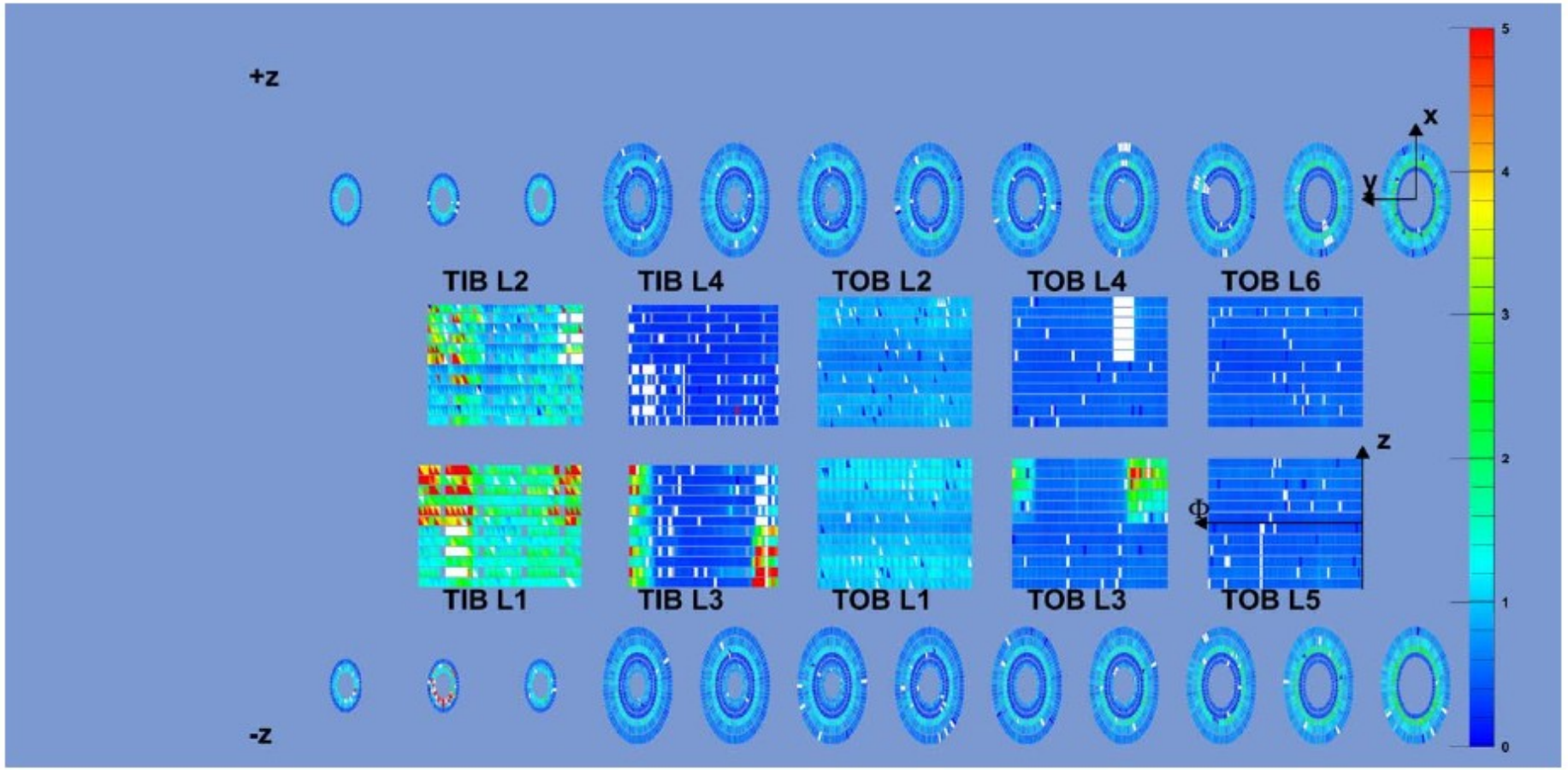
Current Tracker Longevity

- simulated leakage current after 300/fb
  - leakage current still low, except for a few outliers with an inferior cooling contact or closed cooling loop



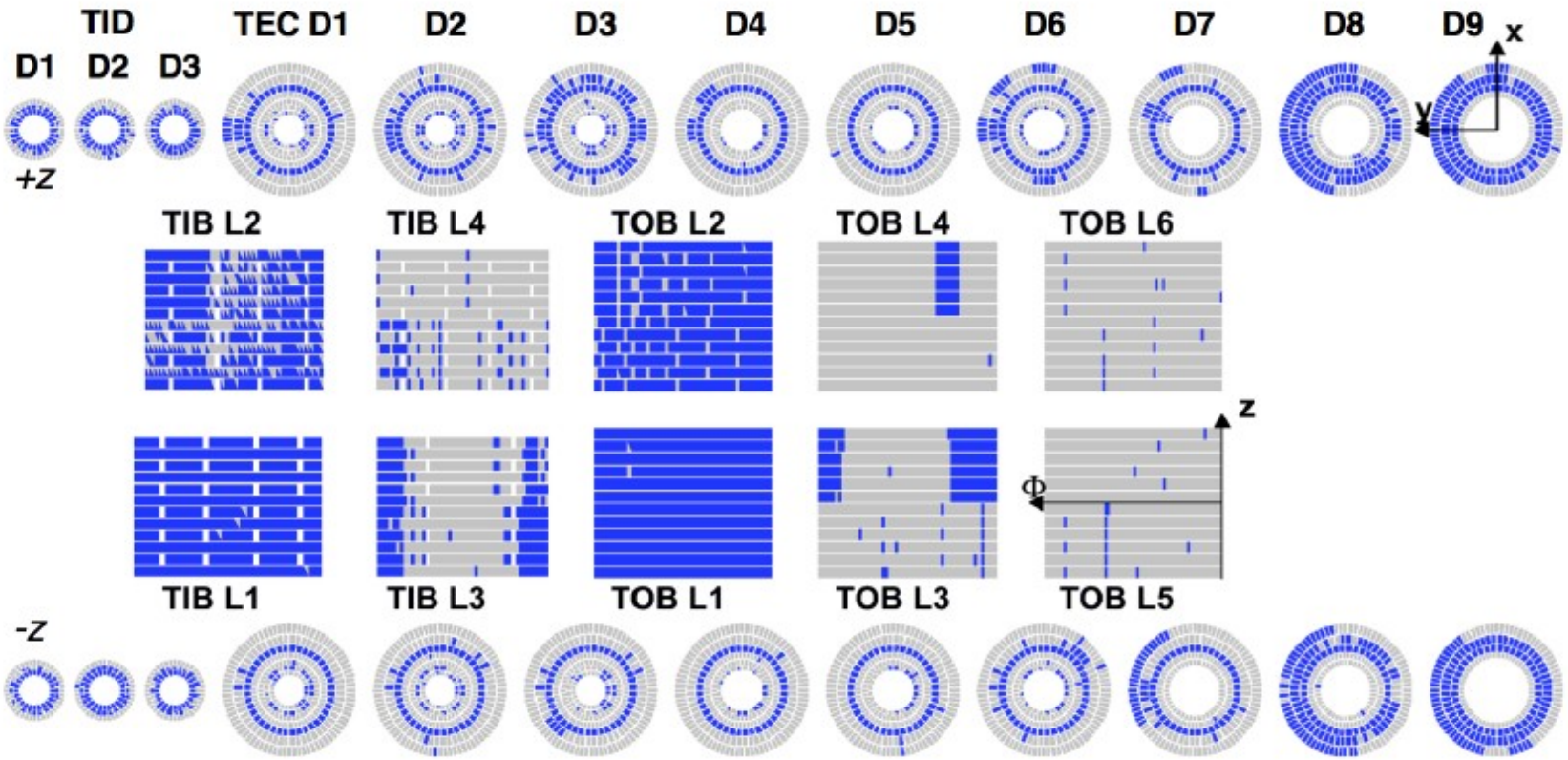
Current Tracker Longevity

- we can make it to 500/fb with cooling fluid at -20C
  - will lose a fraction of uncooled or badly cooled modules



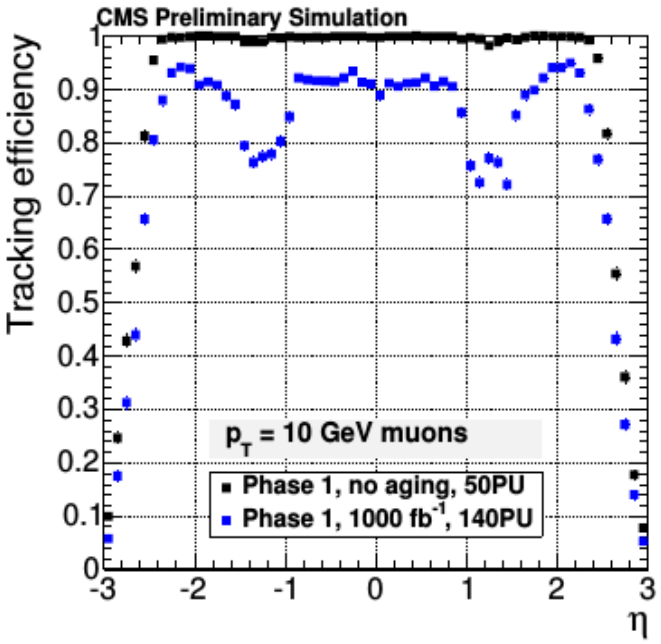
Current Tracker Longevity

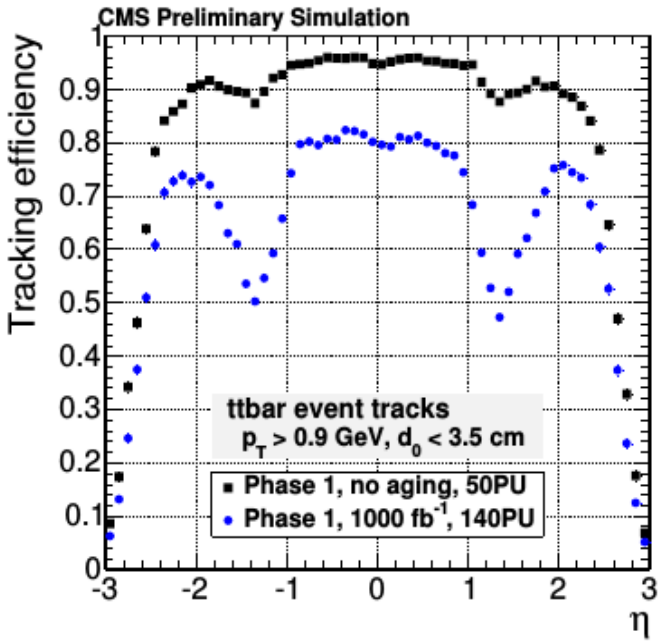
- at 1000/fb, it's game over
  - non-functional modules in blue, for coolant at -20C

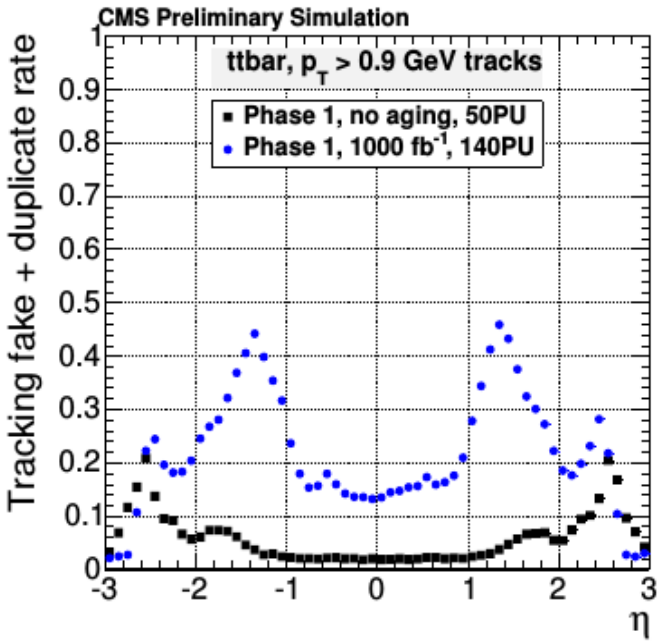


Current Tracker Longevity

- dramatic impact on physics



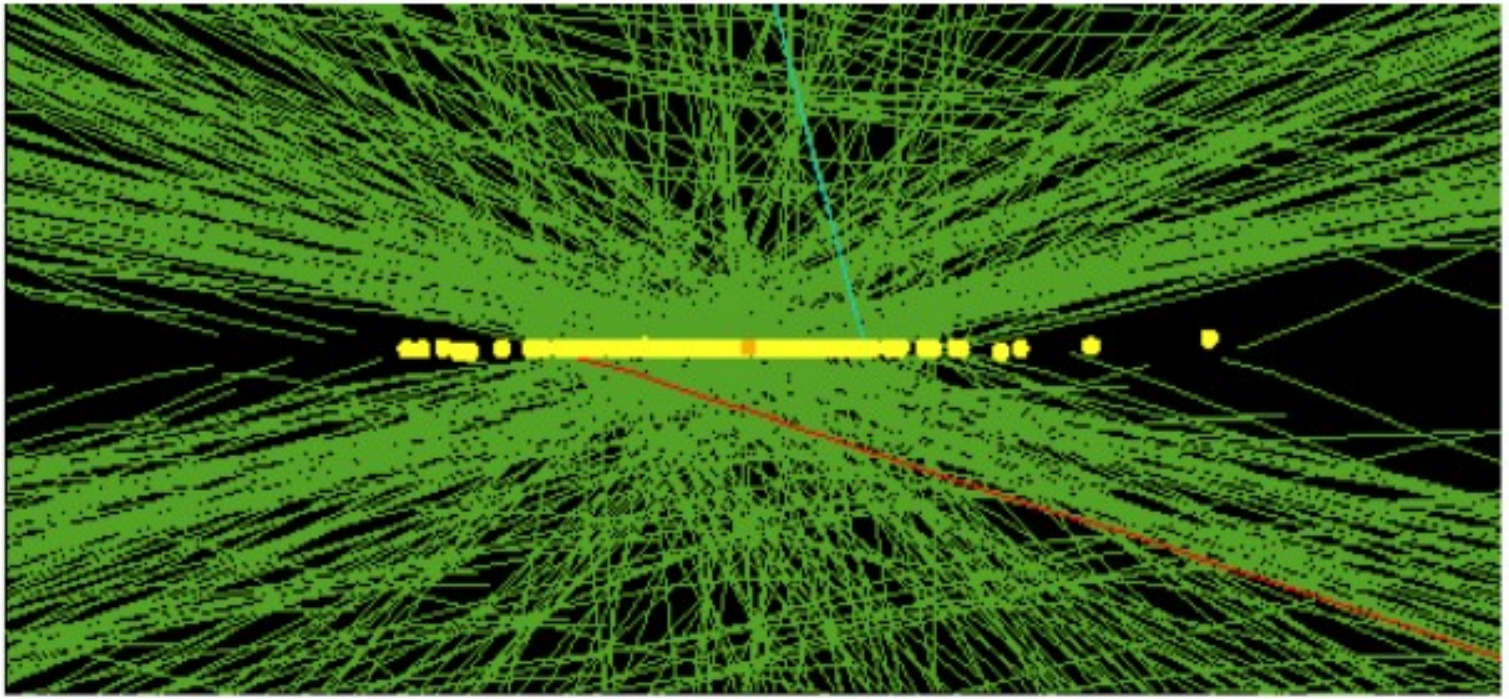




- need new tracker after LS3, by 2026

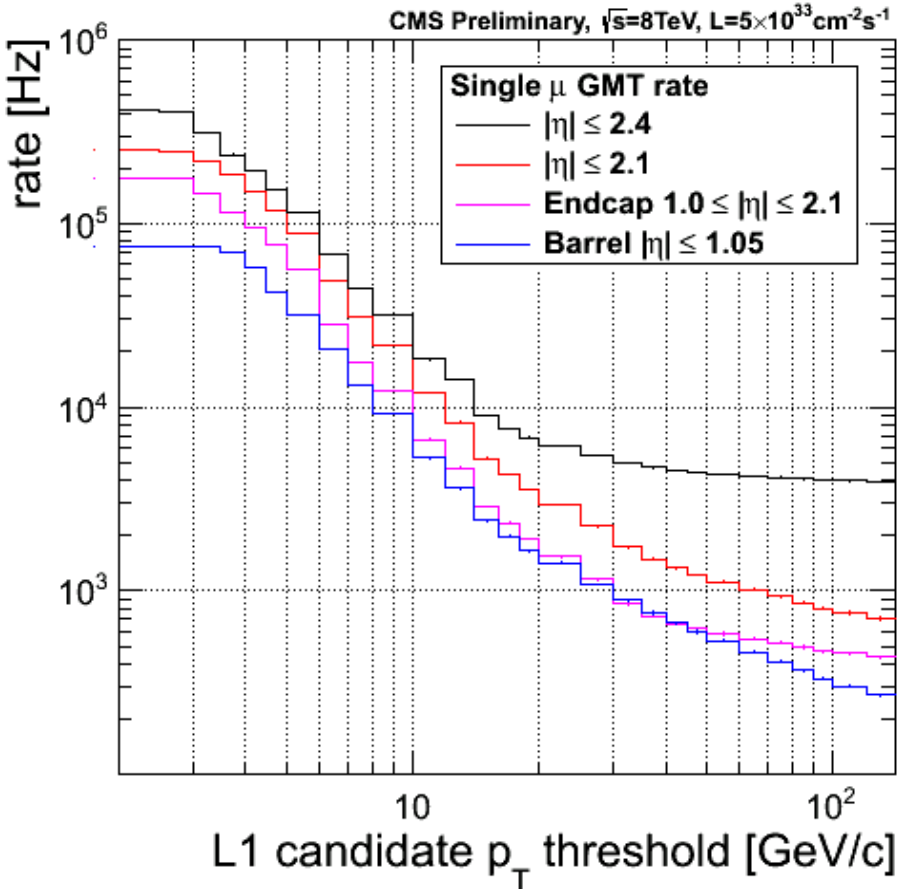
Current Tracker Limitations

- current tracker designed for ~25 simultaneous proton-proton collisions
  - aka pileup
- HL-LHC will take us up to 140 or 200 pileup events
  - need better detector granularity for same tracking performance
- example data event with 78 reconstructed vertices



Current Trigger Limitations

- CMS Level-1 hardware trigger system was designed for very quick selection of interesting events at luminosity up to 10^34 /cm2 /s
  - using coarse readout of calorimeters and muon systems
- HL-LHC aims for lumi x5 and more
- just raising trigger thresholds will kill off most of the physics with muons
  - other objects also badly degraded
- we need the precision of the tracker momentum measurements to join in on the Level-1 trigger decision

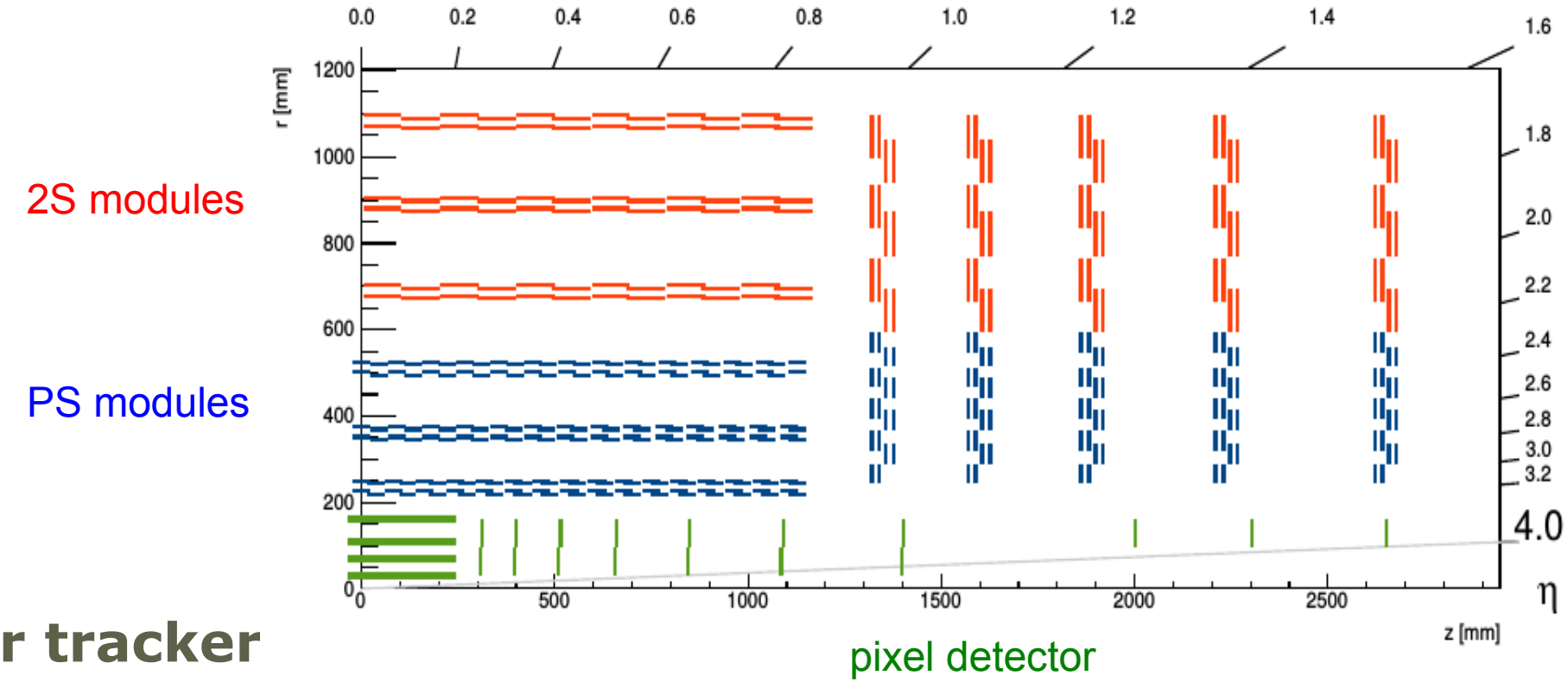


A New Tracker for Phase-II

Requirements on a new tracker for Phase-II

- radiation tolerant
  - design for fluences up to 3000/fb
- increased granularity
  - deal with pileup up to 200 and dense jets
- reduced material
  - mitigate limitation on whole reconstruction from unwanted interactions
- L1 track trigger
  - provide ultra-fast track trigger primitives in fixed latency
- extended tracking acceptance
  - shown to enhance physics program, assigning jets to vertex

A New Tracker for Phase-II



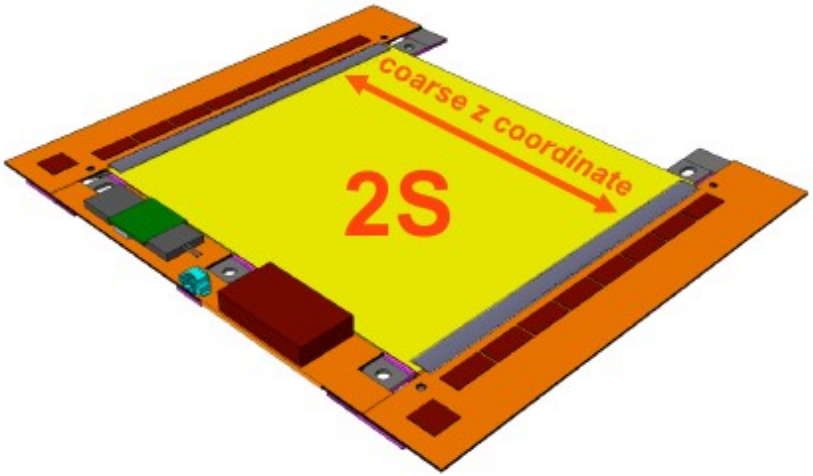
Outer tracker

- 6 barrel and 5 endcap layers
  - 220m2, 15500 double-sided modules, 48M strips, 218M pixels
- binary readout
- light-mechanics, "low" power consumption, CO2 cooling
- 89MCHF for outer tracker

A New Tracker for Phase-II

- module designs

2 Strip sensors
2×1016 Strips: 5 cm × 90 µm
2×1016 Strips: 5 cm × 90 µm
P ~ 5 W
~ 90 cm^2 active area
For R > 60 cm
Spacing 1.8 mm and 4.0 mm



Pixel + Strip sensors
2×960 Strips: 2.5 cm × 100 µm
32×960 Pixels: 1.5 mm × 100 µm
P ~ 7 W
~ 45 cm^2 active area
For r > 20 cm
Spacing 1.6 mm, 2.6 mm and 4.0 mm

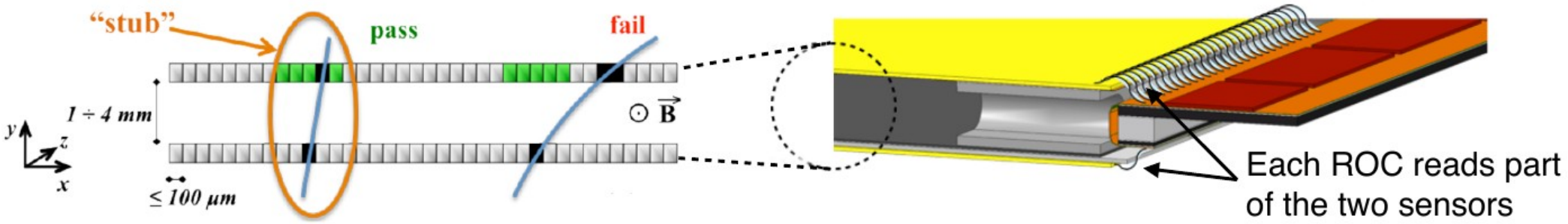
A New Tracker for Phase-II

Outer Tracker pT modules

- serves as basic building block for track trigger

- pT module principle
  - charged particles bend in the 3.8T magnetic field
  - track crossing angle larger for lower pT tracks
  - fast coincidence logic can be used to select "stubs" consistent with pT>2GeV
  - send good stubs on to L1 track finder at 40MHz

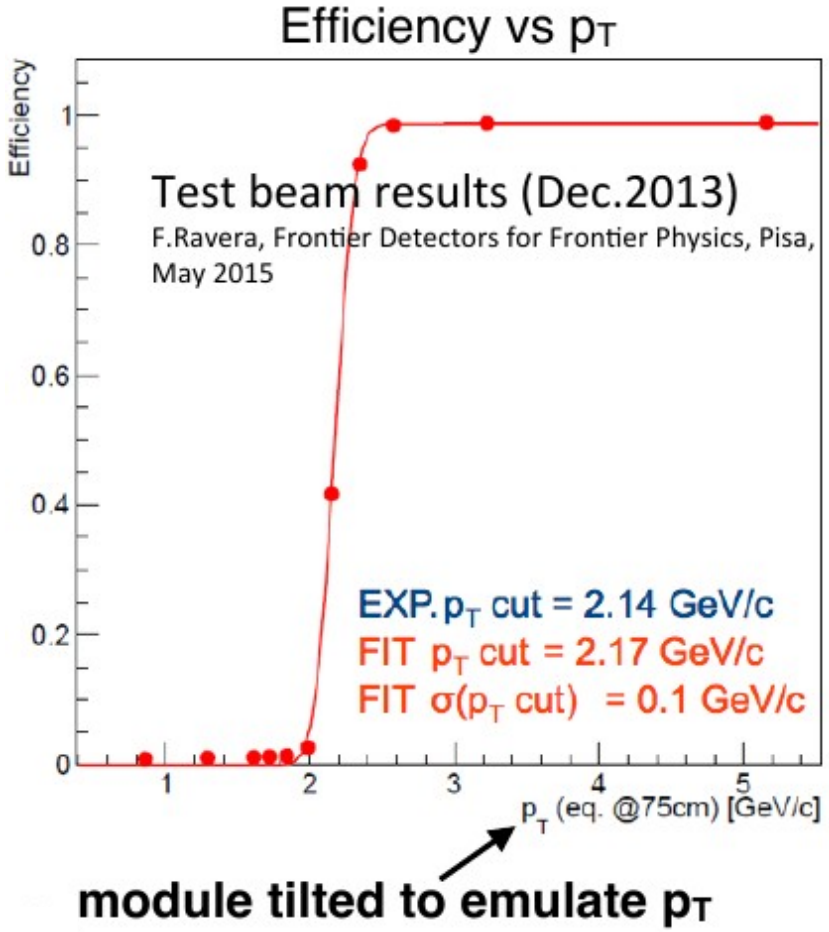
    store zero-suppressed data in buffers waiting for L1 trigger decision

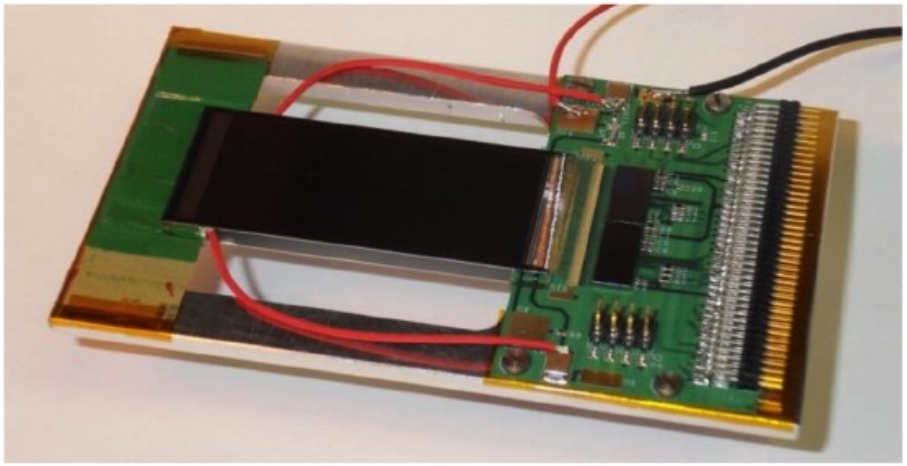


- L1 track trigger is at the core of the new tracker design

A New Tracker for Phase-II

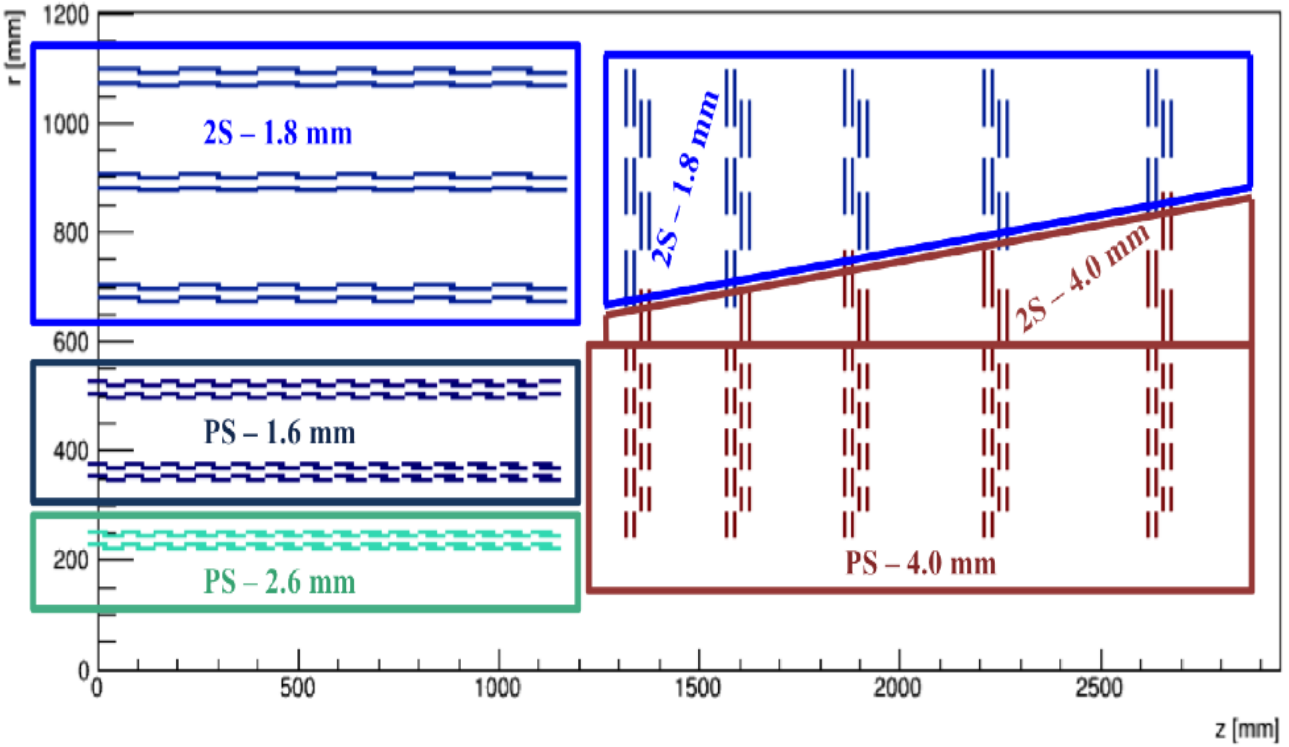
- stub finding verified with prototype in test-beam

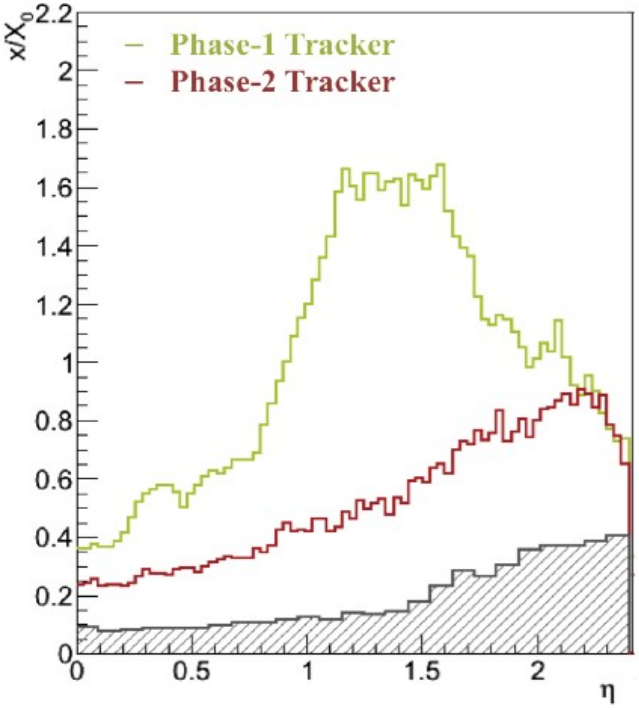




A New Tracker for Phase-II

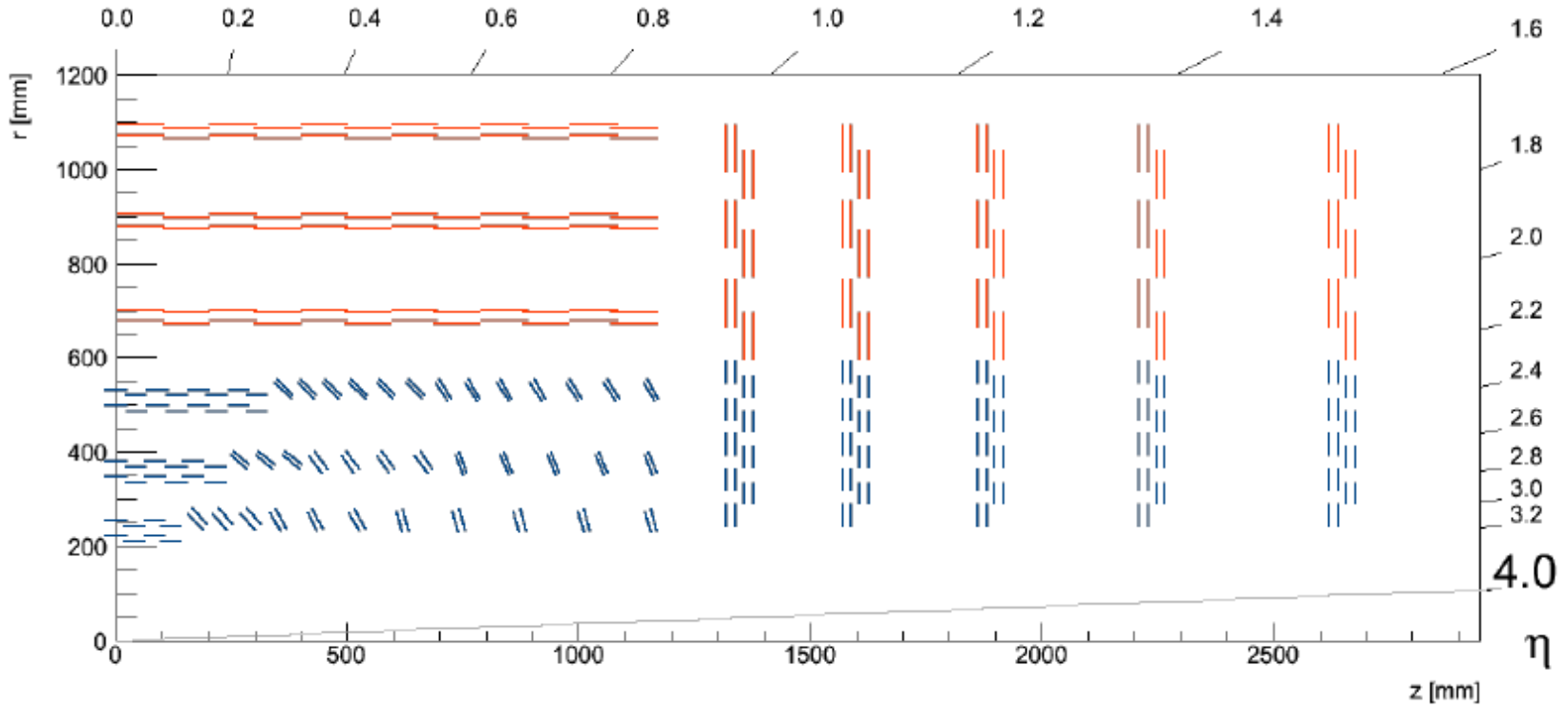
- significantly simpler design than current tracker
  - only a few types of modules
  - each module is an independent detector
  - significantly less material





A New Tracker for Phase-II

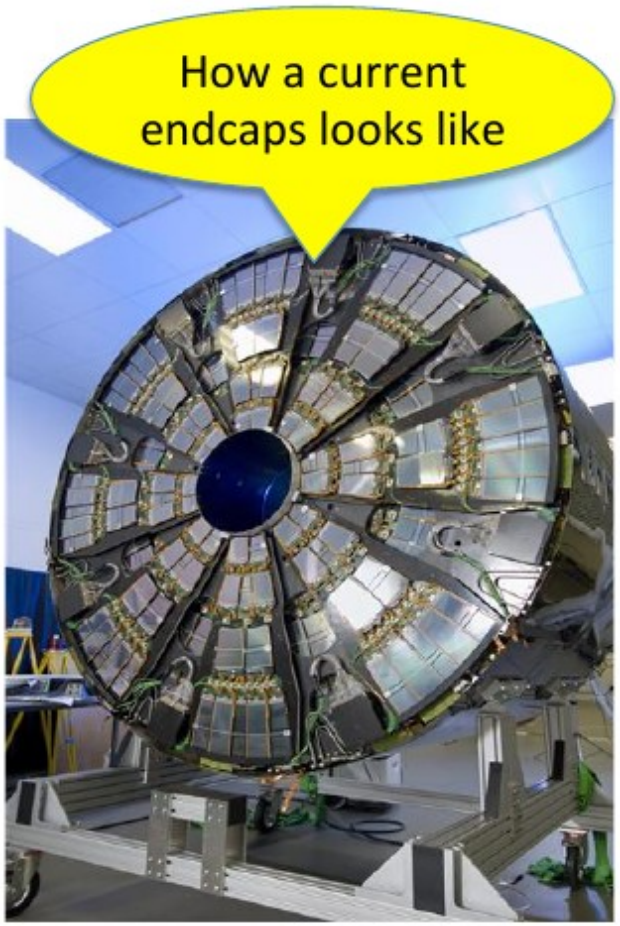
- current developments: tilted barrel geometry

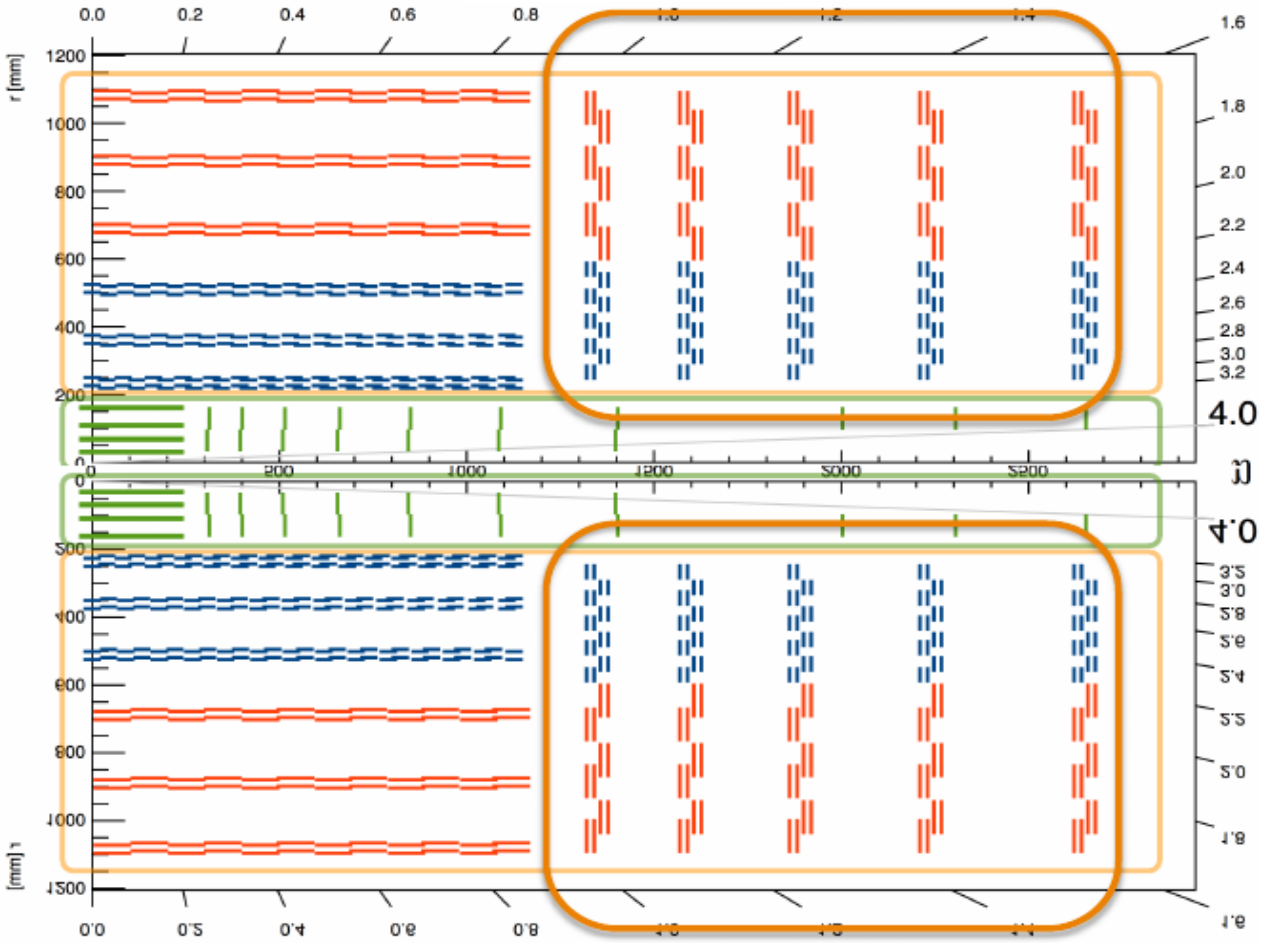


- less modules, less material, cheaper
- equal or better tracking, better stub finding
- slightly degraded z resolution, more work on mechanics

Tracker Ambition in Belgium

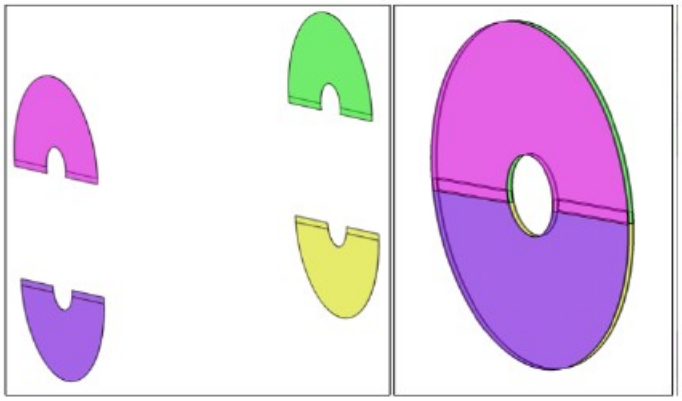
- to integrate 1 outer tracker endcap
- this corresponds to the expected fair-share contribution of Belgium to the CMS Phase-II project

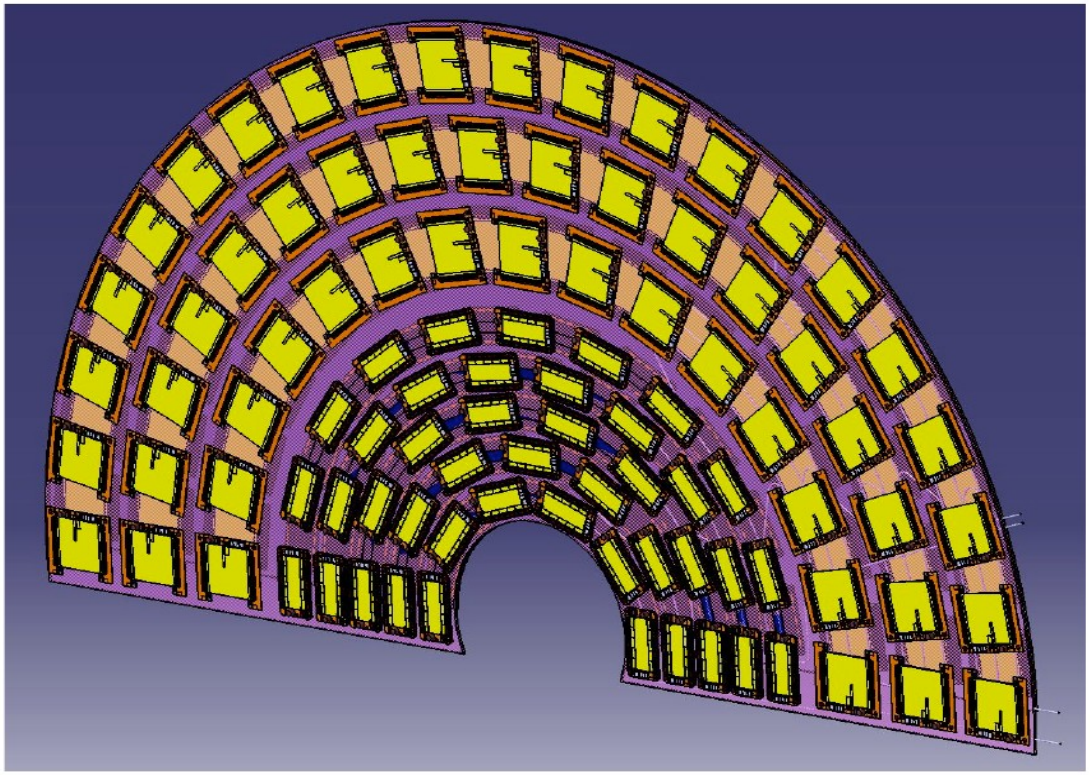




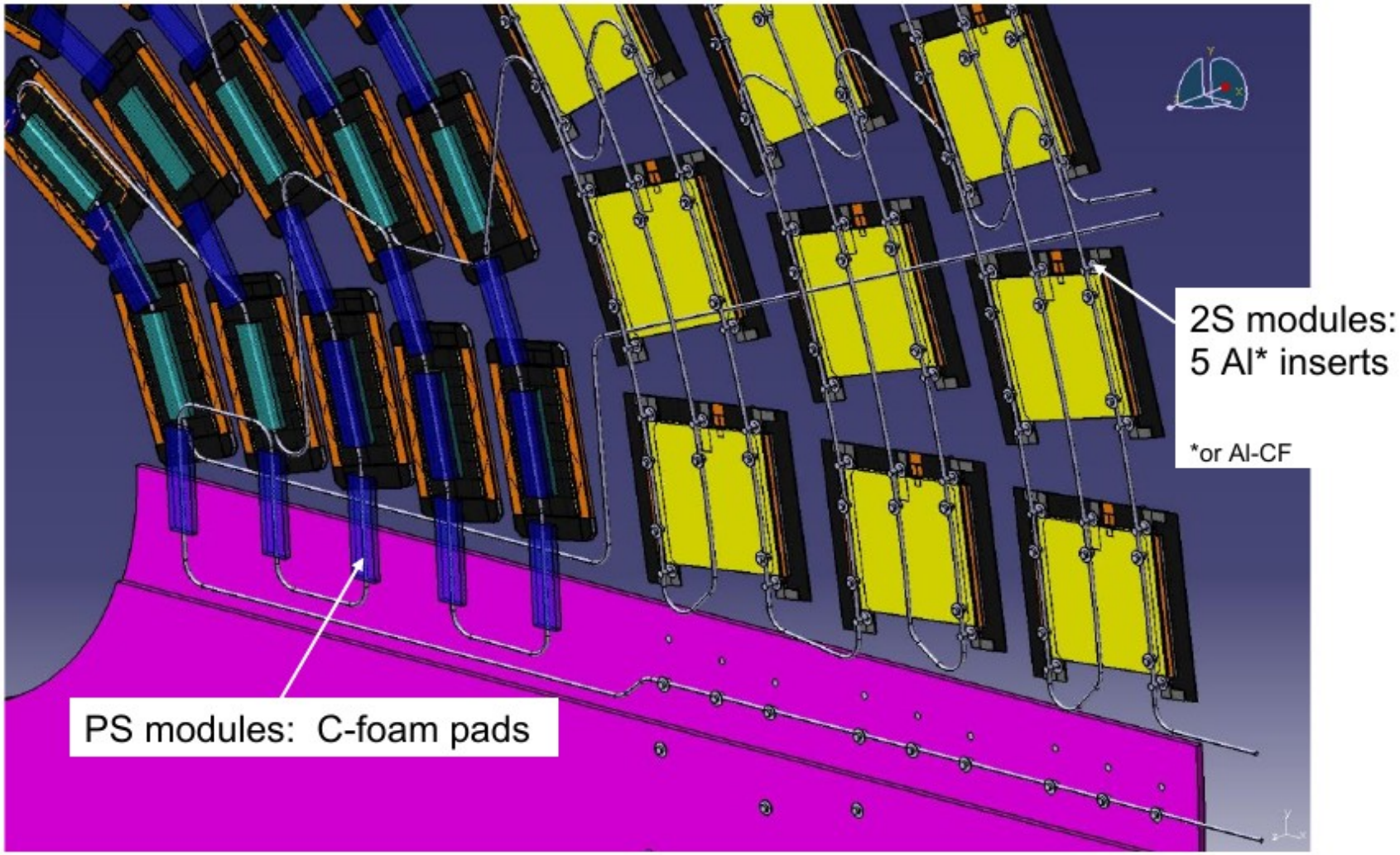
Tracker Ambition in Belgium

- 1 endcap
  - 1 TEDD = 5 Double Disks
  - 1 DD = 4 Dees
- full hermeticity on each DD
- size: 2.5 x 2.5 x 1.5 m3
  - 200kg
  - 20kW power
- mechanical design being worked on
  - 2S modules screwed
  - PS modules glued
- CO2 cooling
  - many advantages
  - but complex





Tracker Ambition in Belgium



Tracker Ambition in Belgium

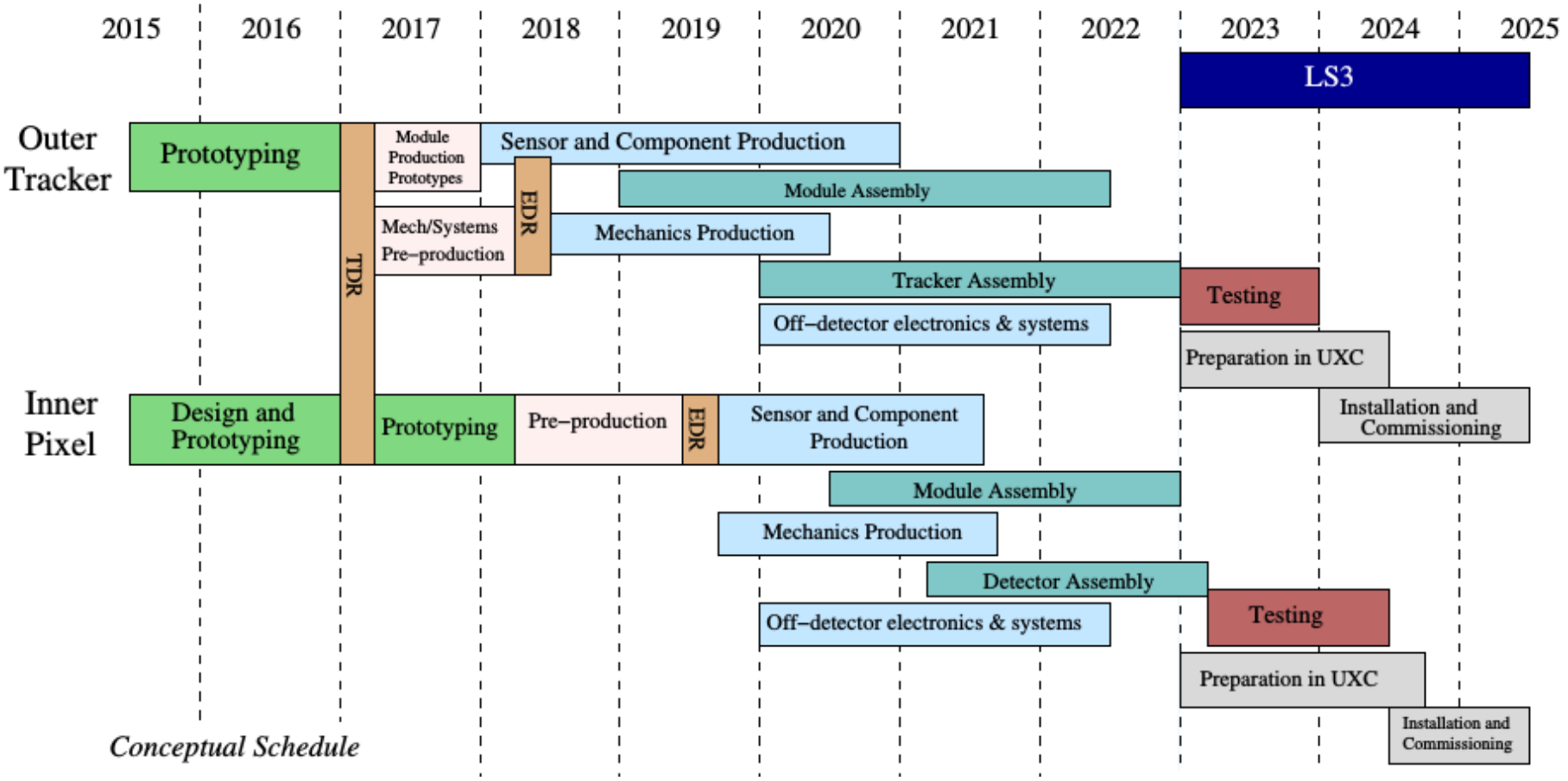
Belgian expression of interest

- the Phase-II tracker is fully supported by the Belgian groups. We would act as a consortium and put our resources together
- our main interest would be in
  - modules full QA
  - Dee integration and test
  - Disk assembly and test
  - TEDD assembly and test
- well received by the tracker management

Funding

- funding request made to the Hercules foundation, ~ equivalent to the Flemish share
  - news expected in January
- the earlier funding situation is clear, the better our position in the tracker

Towards a Phase-II Tracker



Conceptual Schedule

Towards a Phase-II Tracker in Belgium

Current activities

- UCL has a module (one of the only handful!) in a teststand with DAQ setup
  - student and IT contributing actively in testbeams
- new personpower (being) attracted in VUB (student) and ULB (postdoc)
  - start setting up DAQ system, do R&D on module testing, participate in testbeams,...
- UAntwerpen to join when Castor/SoLid hardware commitments go down
  - soon!

- build the consortium from these seeds
  - regular BE meetings
  - discuss news, planning, activities, progress,...
  - develop labs using each others expertise and facilities
  - develop common contacts in TEDD and wider tracker community

Towards a Phase-II Tracker in Belgium

Other current activities

- software involvement
  - contributions to geometry, simulation, and local reconstruction
  - Christophe current convener of Phase-II simulations & local reco group
- track trigger interest
  - ULB postdoc working on studying potential benefit from usage of different architectures (FPGA, CPU, GPU,...)
  - we have a clear interest to extend this to a direct involvement in track trigger developments

Conclusions

- the HL-LHC will be the next frontier at CERN, from 2026 onwards
- the CMS tracker must be replaced for the HL-LHC
- a new LHC tracker is to be constructed
  - radiation hardness up to 3000/fb
  - capable to deal with 200 overlapping collisions
  - track trigger
- Belgian common ambition for future CMS tracker construction laid out
  - positively welcomed by tracker management
  - Hercules grant applied for
  - labs starting to prepare towards the future

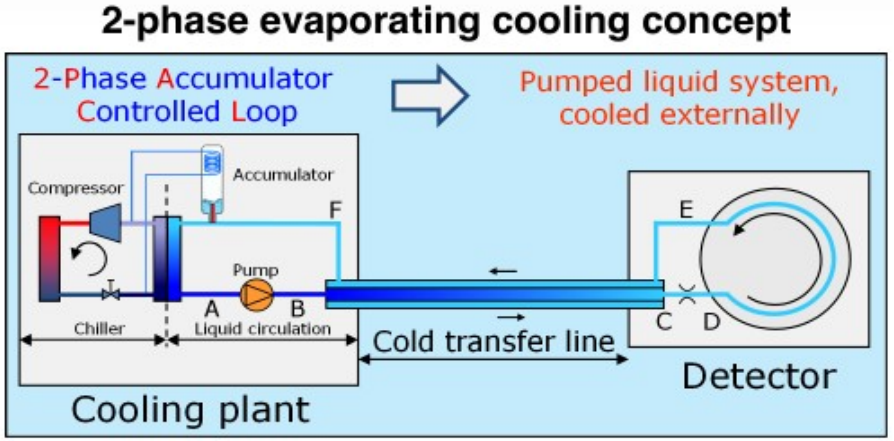
Backup

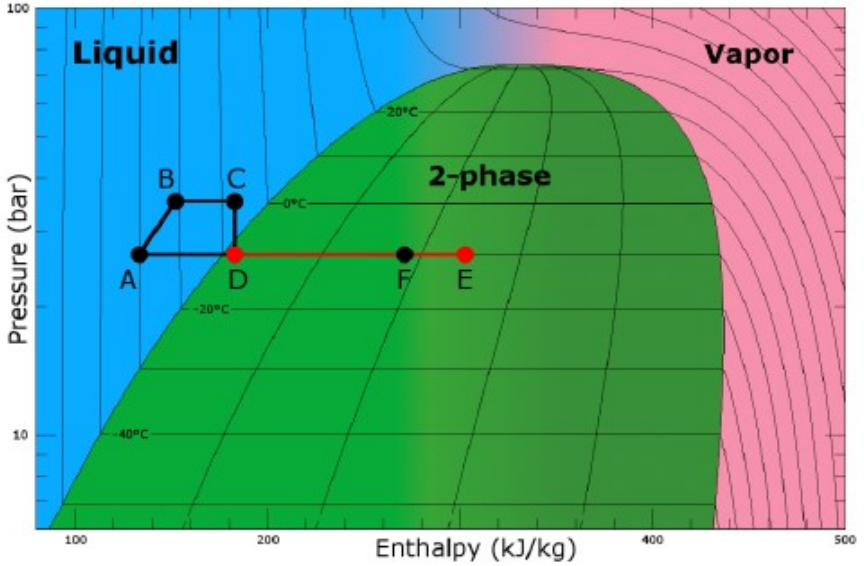
CO_2 Cooling

Advantages of CO_2:

- Large latent heat
- Low viscosity
- Very small pipes → Low mass
- Cheaper than fluorocarbon refrigerant
- Low impact on environment

CO_2 cooling foreseen for Phase-1 upgrade
The technology in principle allows scaling to full tracker (between 5× and 10× w.r.t. pixel)





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