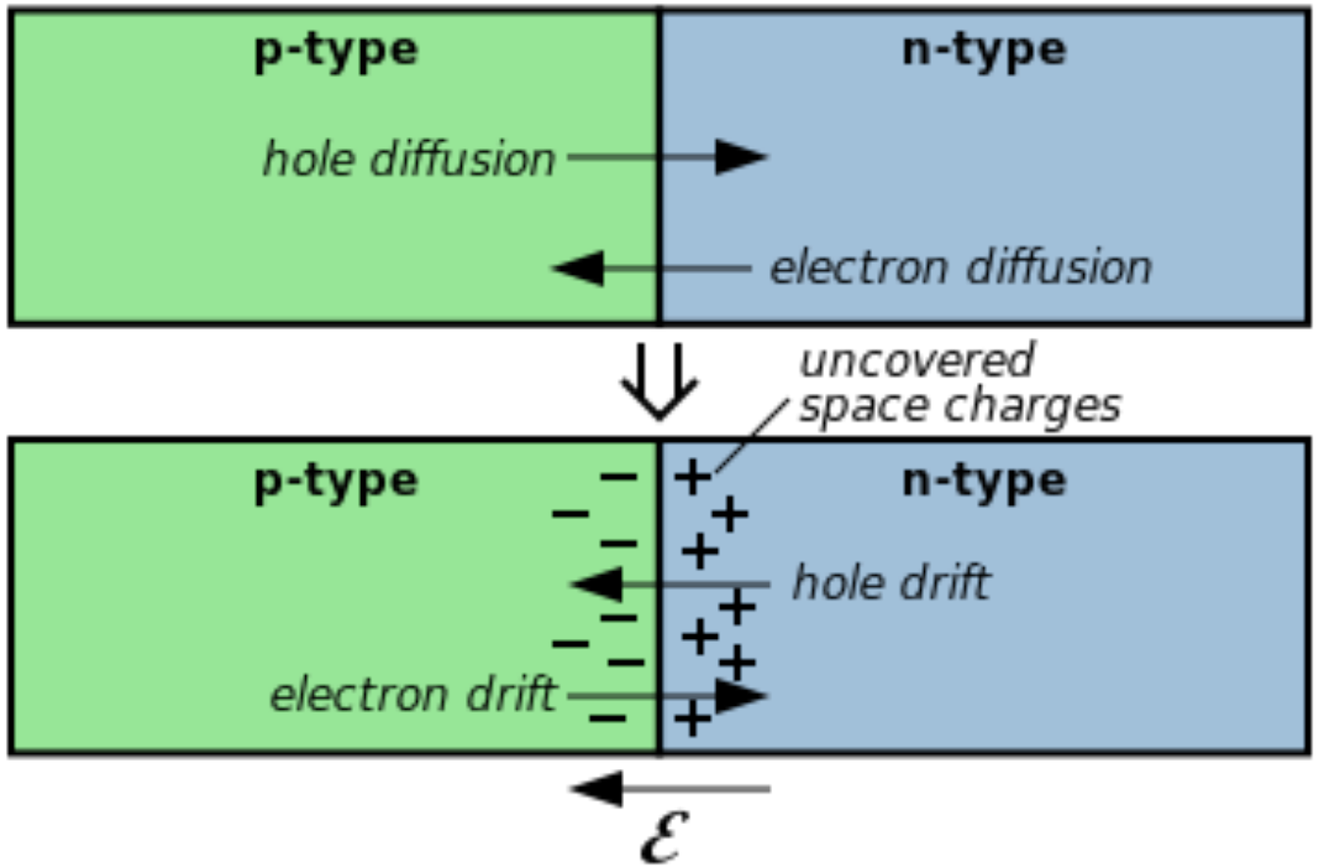
Phase 2 Tracker Upgrades at CMS

Perimeter Institute Seminar

Salvatore Rappoccio
(State University of New York at Buffalo)

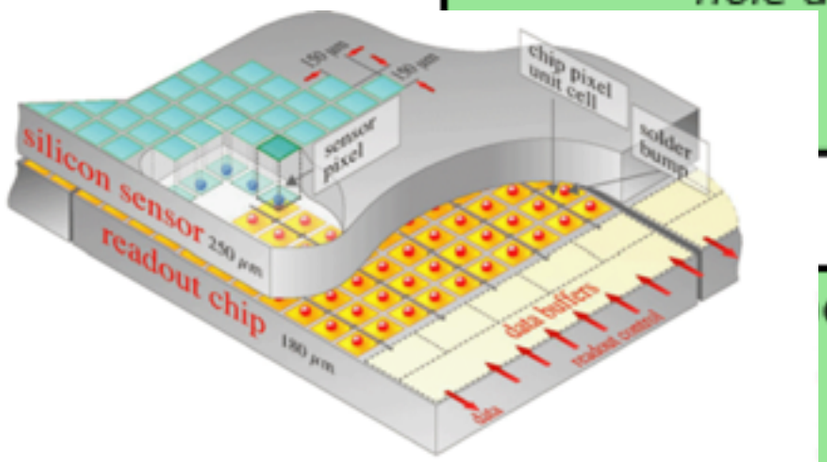
8 June 2015

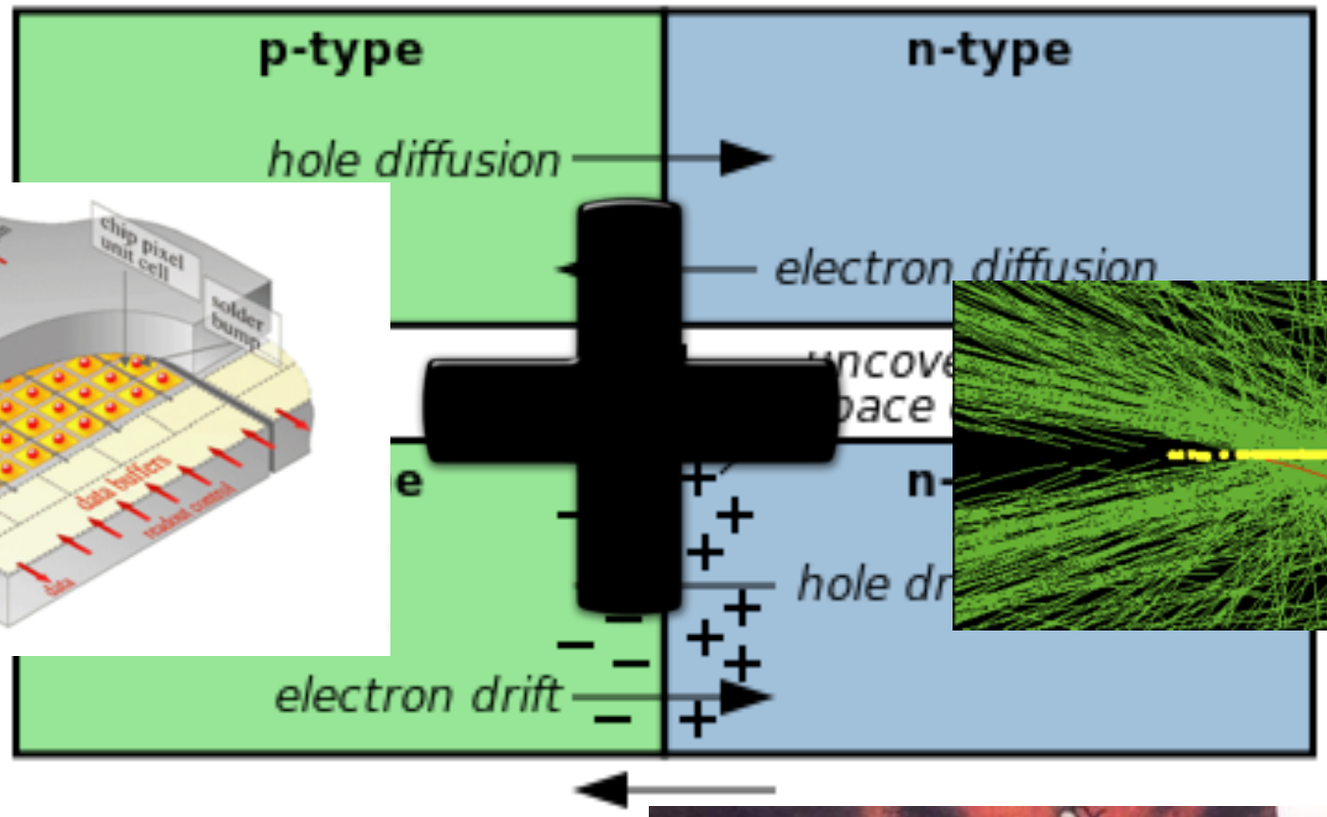
Reminder of Solid State Physics

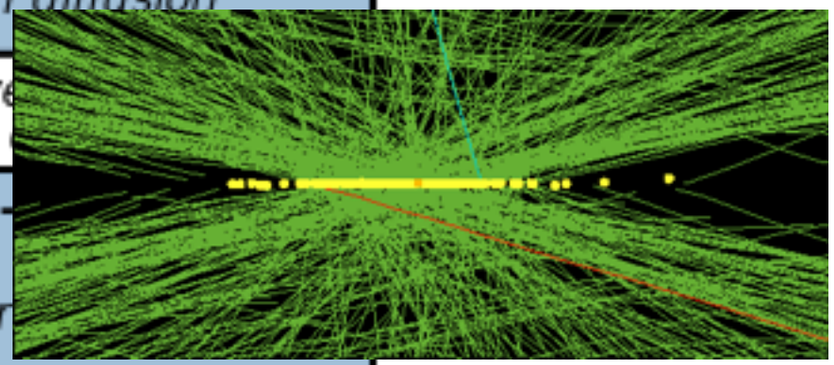


- Apply voltage to p-n junction, creates region “depleted” of charge carriers
  - Then sensitive to ionization (i.e. detected particles)
  - This is how our detectors work
- Radiation degrades solid-state lattice of the doped semiconductor
  - Need higher and higher bias voltage to deplete, until it is ineffective
- Also increases leakage current

Reminder of Solid State Physics

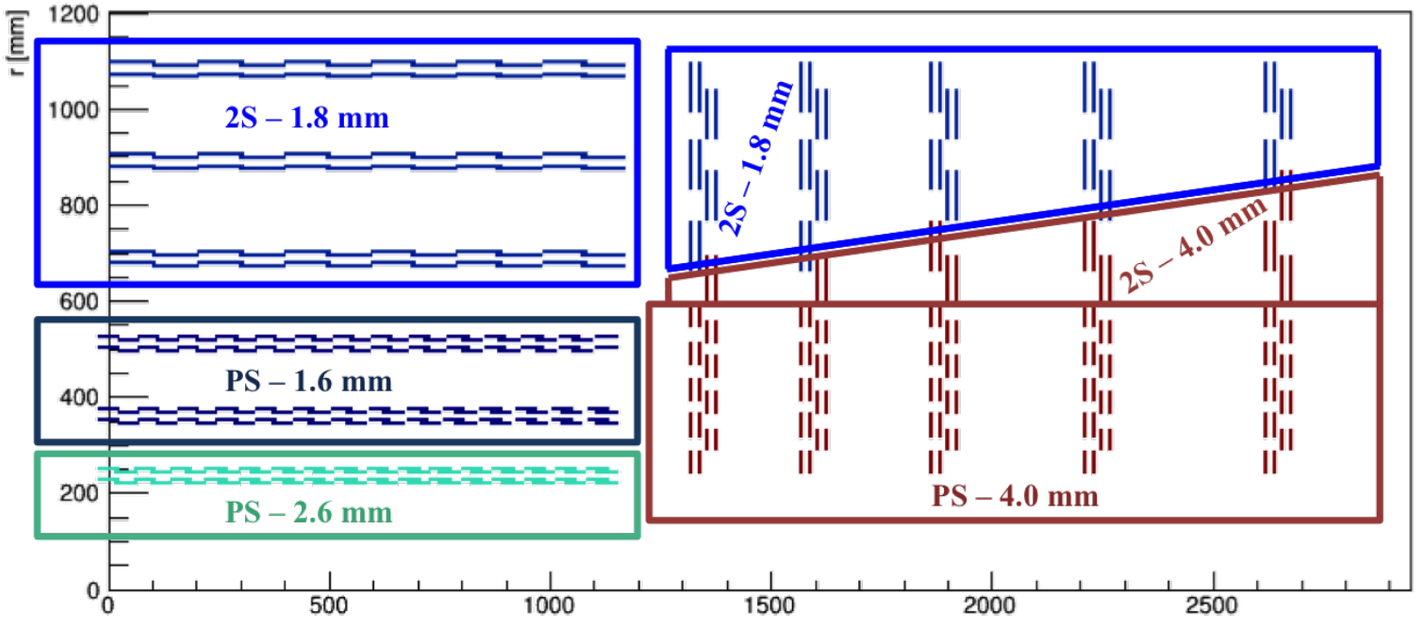




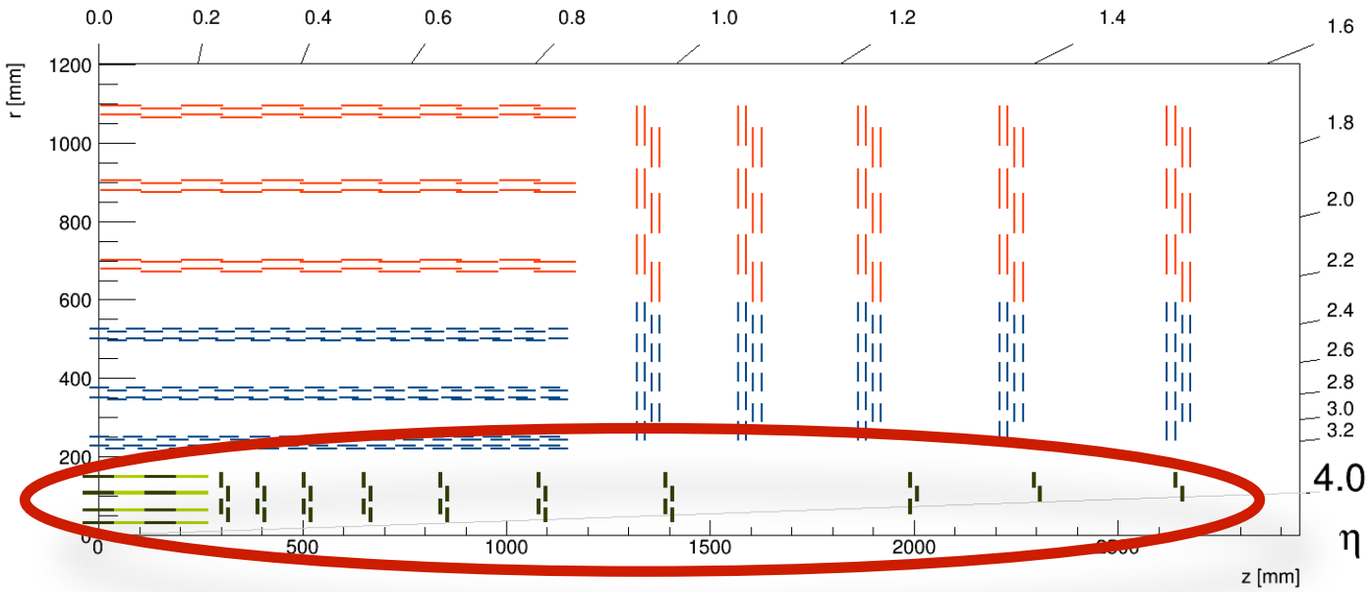


- Apply voltage to p-n junction, c[redacted]f charge carriers
  - Then sensitive to ionization ([redacted]
  - This is how [redacted]ors wo[redacted]onductor
- Radiation degrades solid-state [redacted]onductor
  - Need higher and higher bias voltage to deplete, until it is ineffective
- Also increases leakage current

Reminder from Joe's talk



- 220 m² area - 15500 modules
- 50M strips - 220M macro-pixels
- 90/100 µm pitch (2S/PS modules)
- 2.5/5 cm strips (2S/PS) - 1.5 mm macro-pixels in PS modules
- 200 µm active or physical thickness

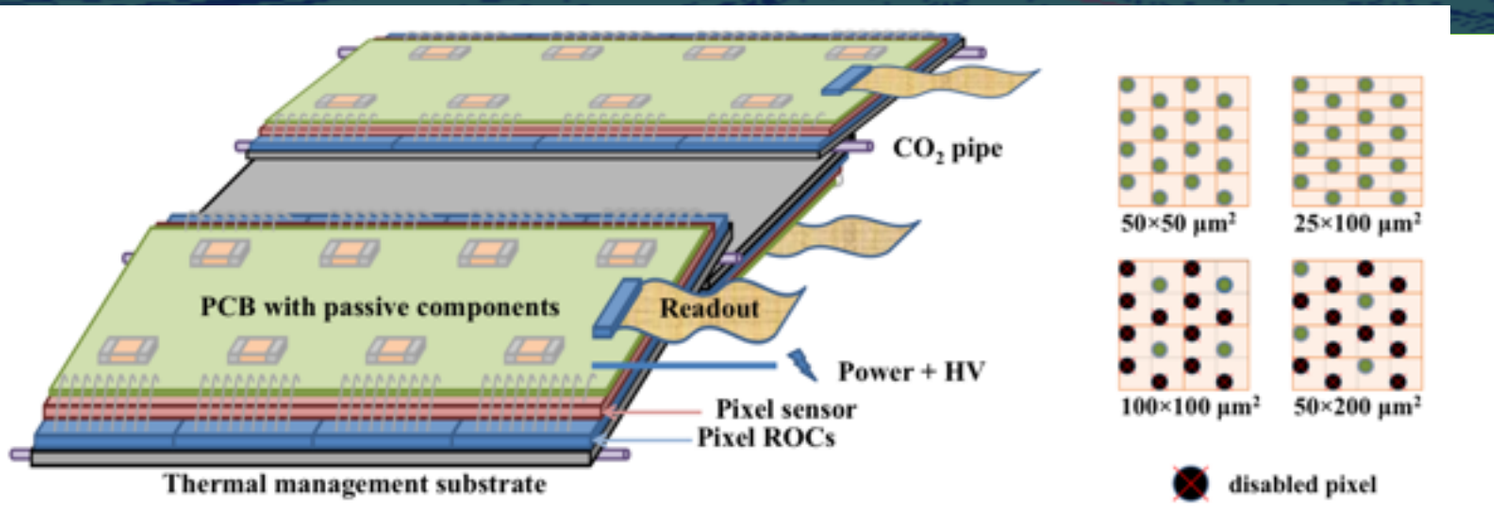


- Pixels
  - Barrel: 4 layers at 3, 7, 11, 16 cm
  - Forward: 10 disks to η = 3.8
  - Data readout at 750 kHz

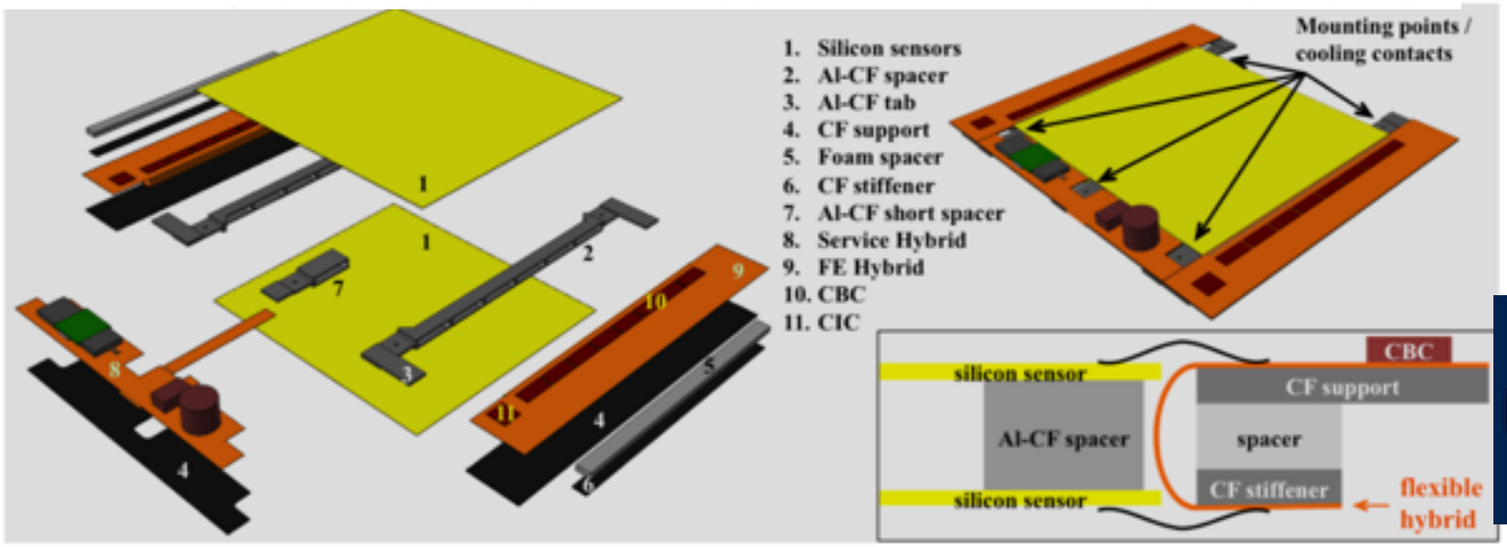
- Total pixel area ~ 4 m²
- 50x50 to 25x100 µm² pixels
- ≤ 150 µm sensor physical thickness

Overview

Pixels

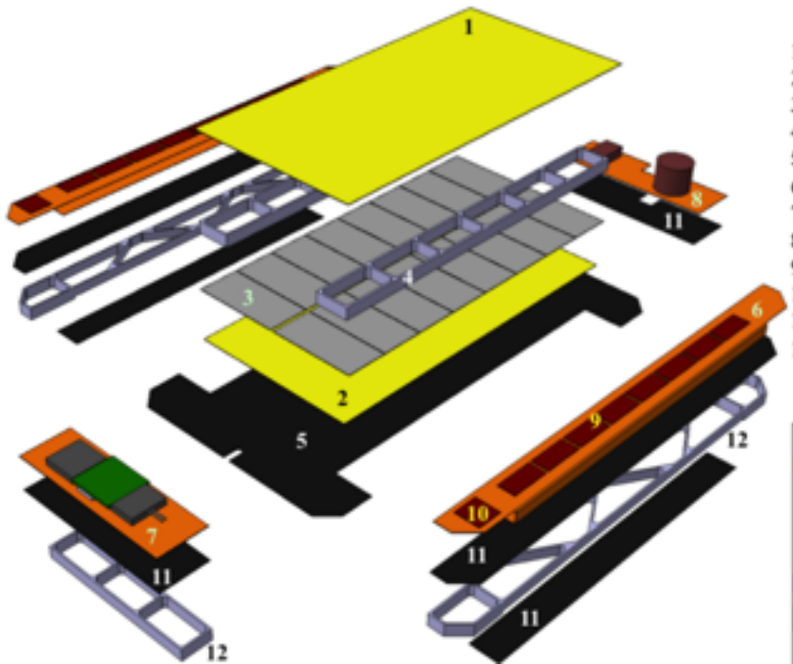


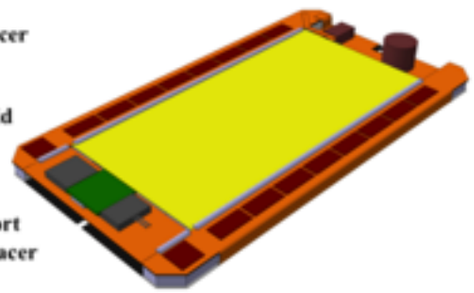
Strips

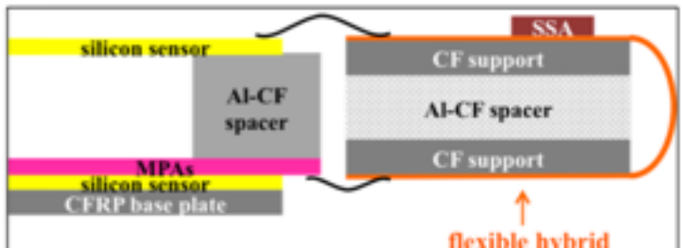


Design choices largely based on “breaking even” with current capability

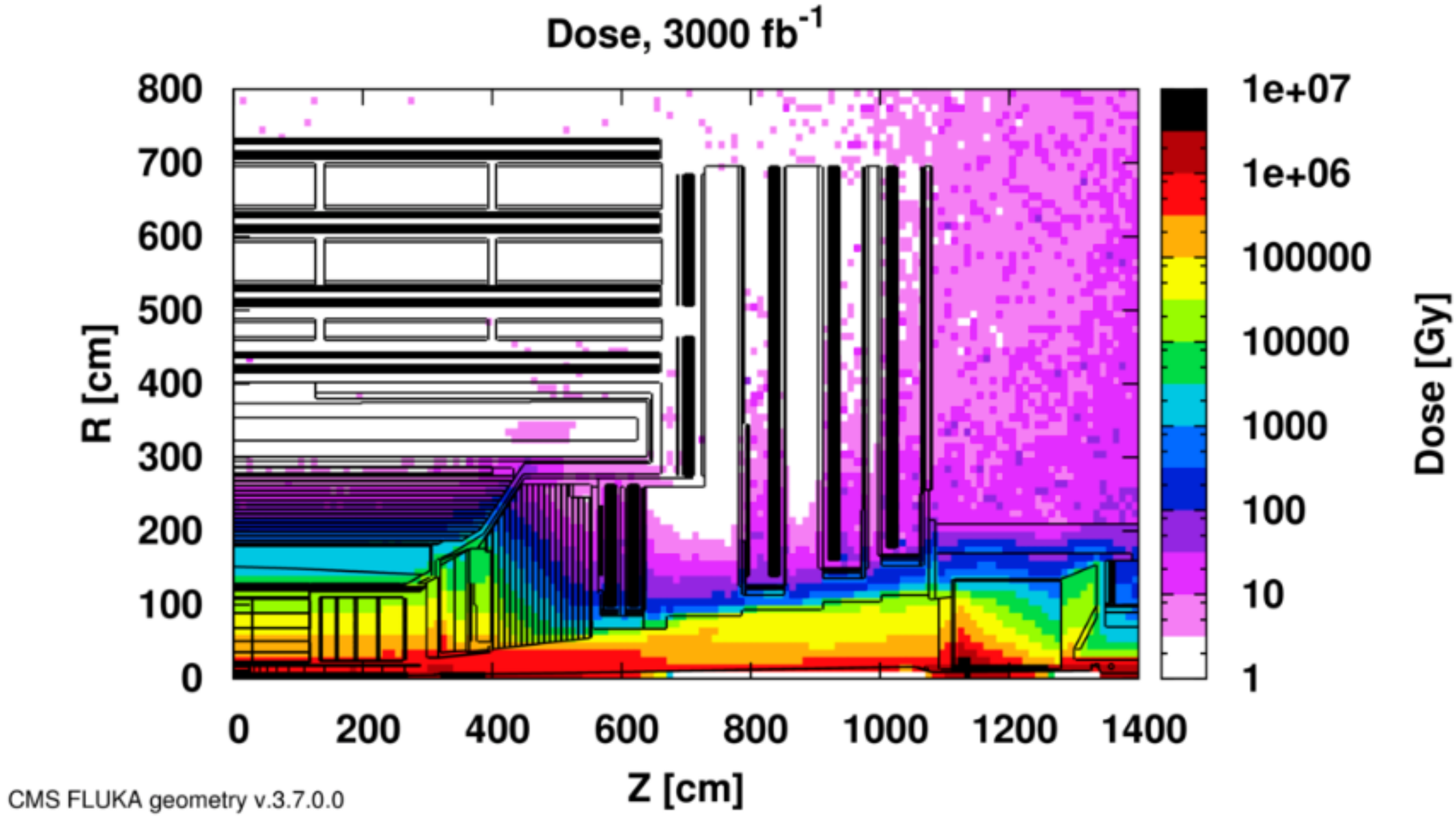
Pixel strips



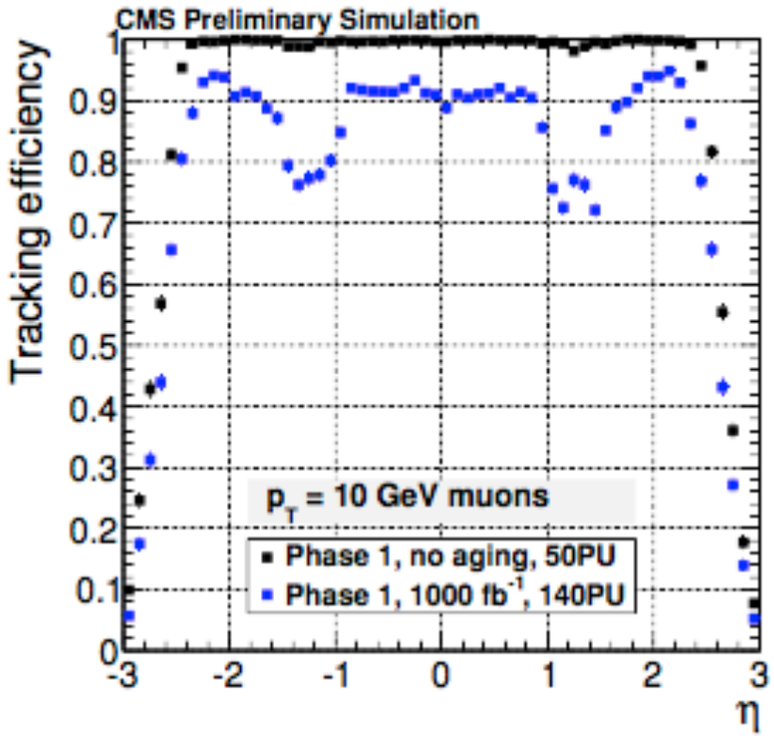


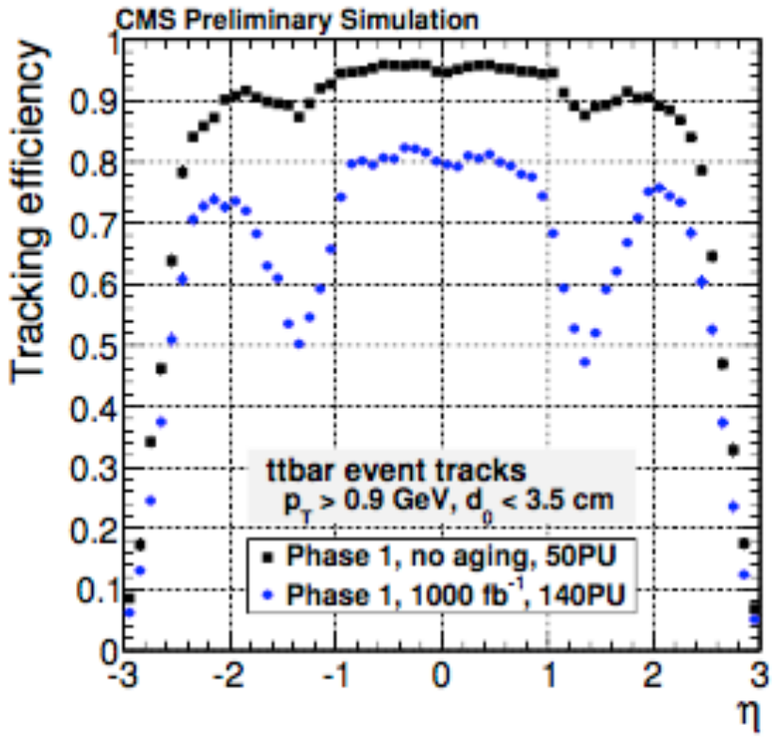


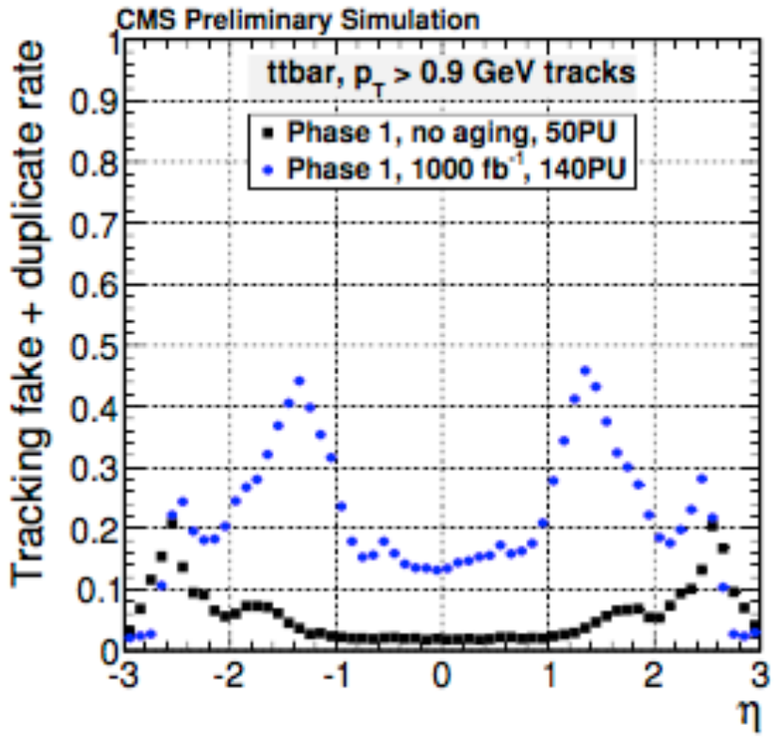
Challenge 1 : Radiation



Challenge 1 : Radiation



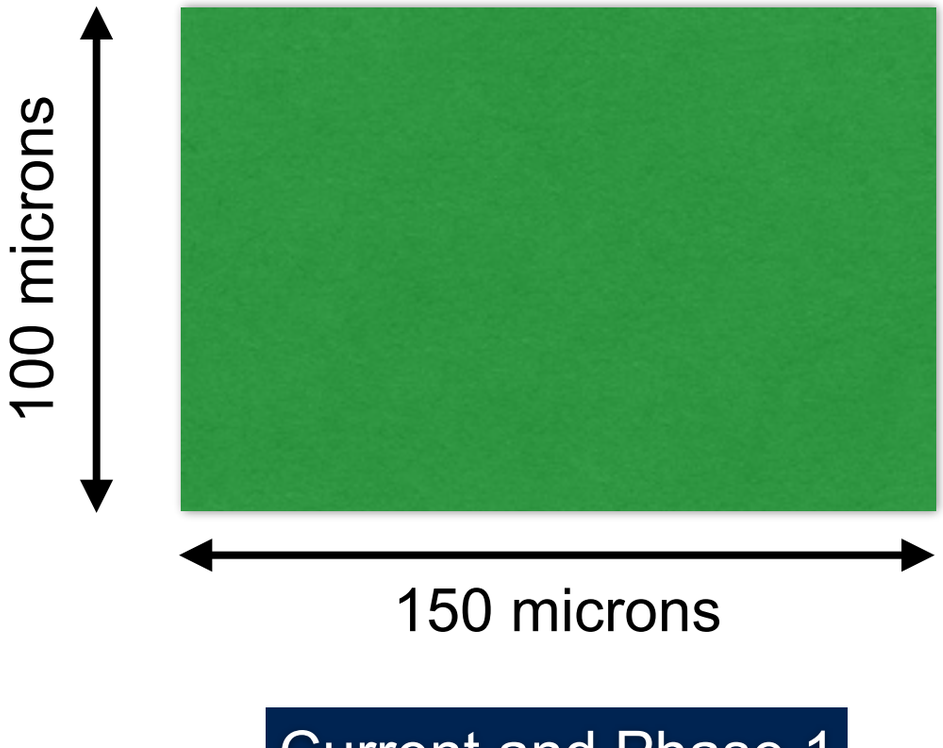


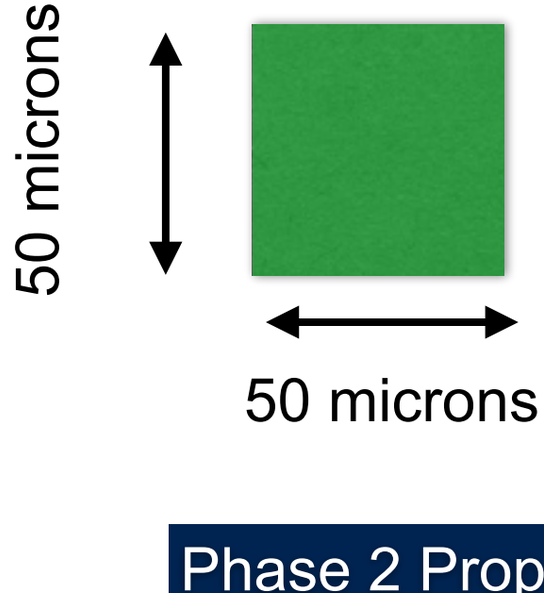


- Phase 1 detector (pixels and outer tracker) have no hope for HL-LHC

- Moral : We need to replace the pixels twice (Phase 1 and Phase 2), and the tracker once (Phase 2)

Challenge 2 : Pileup



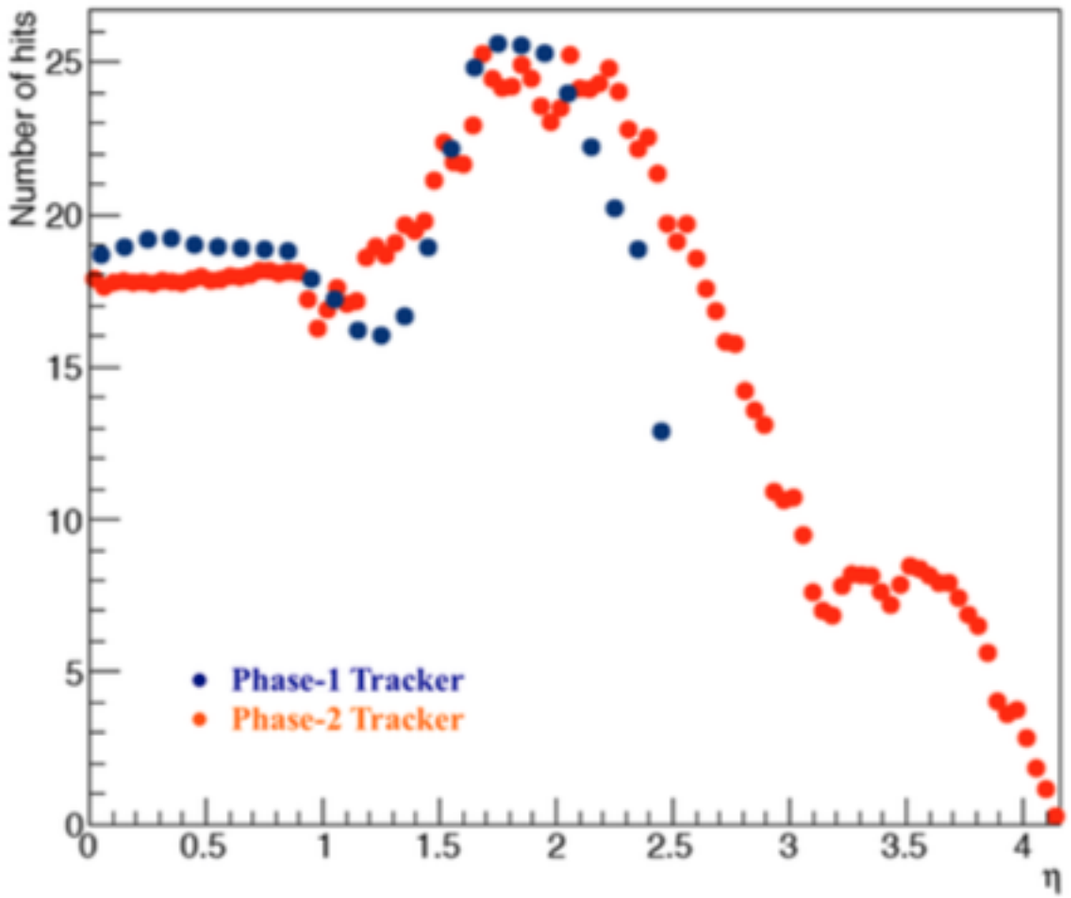


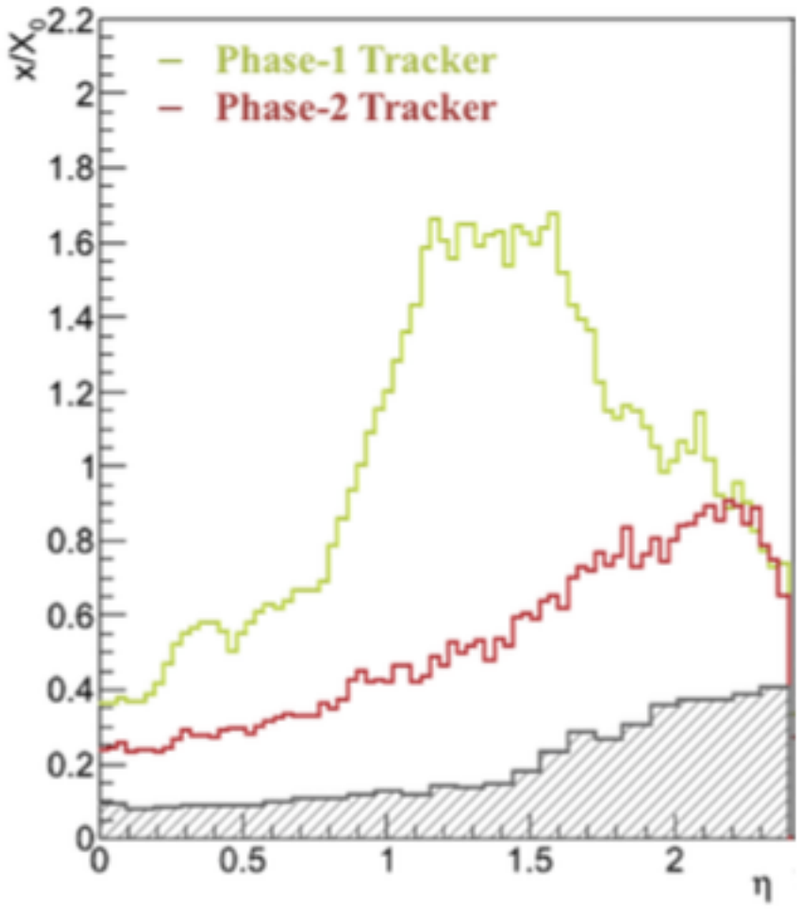
Current and Phase 1

Phase 2 Proposal

- 140 pileup interactions means the current detector has more than 1 hit per silicon module on average
- Moral : need higher granularity (smaller modules)

Challenge 3 : Both less and more in the tracker

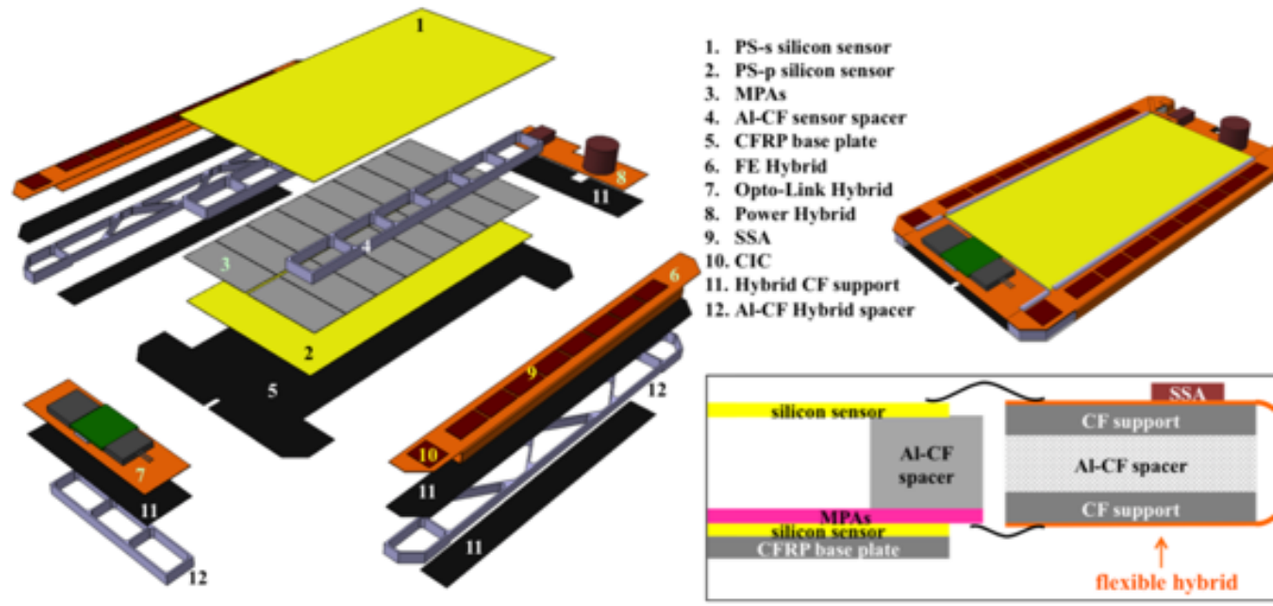


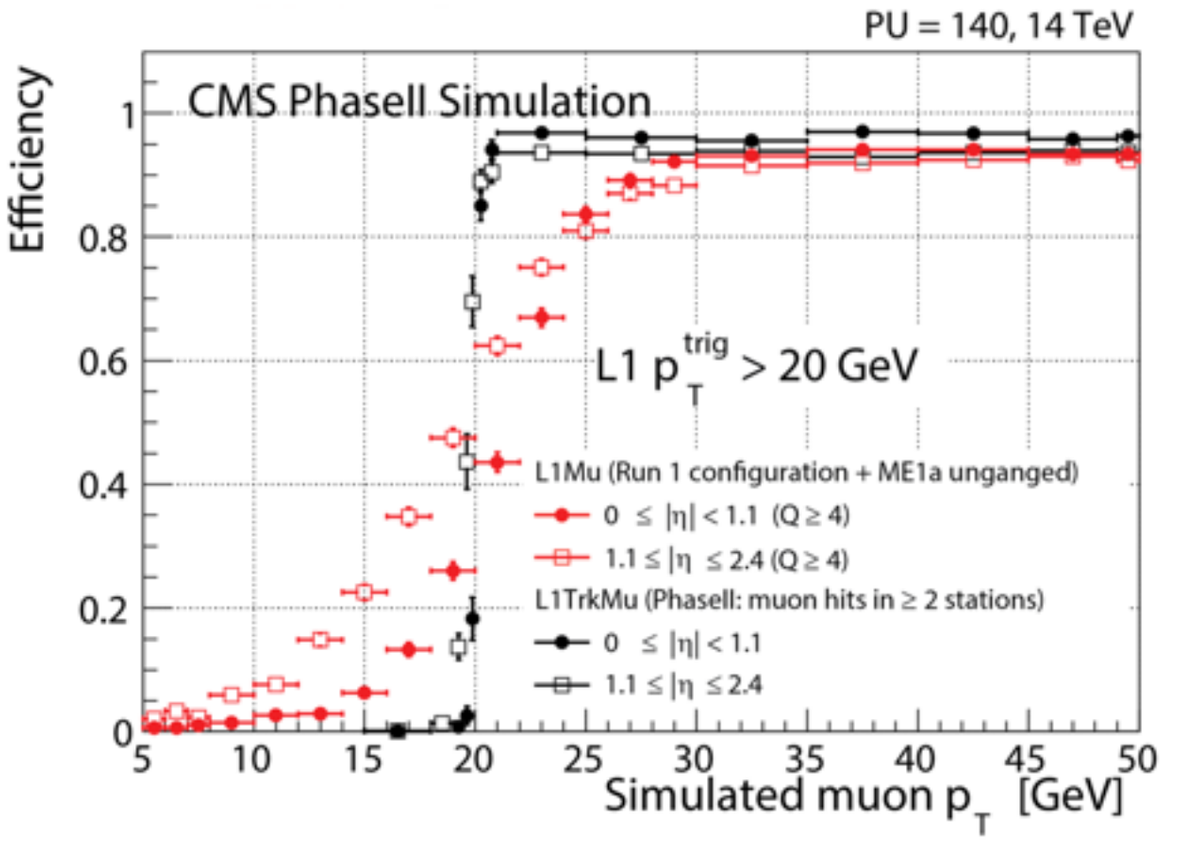


- Dense trackers cause conversions and interactions, degrades resolution overall (tracking, electrons, photons, jets, MET, and muons)
- “Higgs and nothing else” scenarios desperately need VBF channels
- Moral : more coverage, and lighter support for better resolution overall

What's New?

- Technology?
  - So far most likely to be "tried and true" semiconductor devices
    - Exception is slightly advanced modules of silicon
      - "Pixel strips", "Macro pixels",
    - Some R+D for other options (diamond, etc)
  - New L1 trigger
    - Tracking at L1… what can we do there besides "breaking even"?
    - Discussion this afternoon!





Scenarios for Tracking

- **Scenario 1 : New physics in Run 2 / 3 : “Resolved” topologies**

  - Examples : “Bulk” SUSY, 2HDM
    - Prototypical selections : Isolated leptons pt > 20 GeV, jets pt > 20 GeV, MET > 20 GeV

  - For the tracker :
    - Need good b-tagging, forward coverage, low mass detectors, good electron and muon matching, etc
    - Tracker + L1 trigger necessary to keep thresholds low

  - Theory Inputs :
    - Interpretations, interpretations, interpretations
    - MC tools (N^i LO, i=1,2…) ?
    - Specifics : LHE files of various models?
    - Cleverness (many hands, light work, etc)

Scenarios for Tracking

- **Scenario 1 cont'd : New physics in Run 2 / 3 "Boosted" topologies**

  - Examples : VV/VH/HH, ttbar, VLQs, etc
    - Prototypical selections : Isolated + nonisolated leptons pt > 50 GeV, jets pt > 200 GeV, MET > 20 GeV

  - For the tracker :
    - Mitigate track and hit merging from geometry of boosts
    - Trigger thresholds need not be too low
    - Forward coverage important mainly for VBF modes and MET resolution

  - Theory Inputs :
    - Same as resolved topologies, but a few others :
    - Jet and substructure calculations
    - QCD NNLL and NNLO anything

Scenarios for Tracking

- **Scenario 1 (continued) : New physics in Run 2 / 3 “Invisible” or “Displaced” topologies**

  - Examples : “Compressed” SUSY, Higgs portals, hidden valleys, etc
    - Prototypical selections : Displaced tracks, many low-pt objects, Higgs -> invisibles

  - For the tracker :
    - Critical need for forward coverage, good electron and muon matching, may even benefit with a larger tracker or muon chamber
    - Tracker + L1 trigger necessary to keep thresholds low

  - Theory Inputs :
    - Same as resolved topologies, but a few others :
    - Ideas of what we may be missing and how to improve
    - Think outside the box

Scenarios for Tracking

- **Scenario 2 : New physics hints in Run 3**
  - Difficult to predict. We will have hints by definition. What to follow up with?
  - For the tracker :
    - Same as above, really
  - Theory inputs
    - Comprehensive consistency checks for a variety of models among a myriad of channels (and not just non-compressed SUSY)
    - Precision calculations, new observables?
    - Pulling out signals that are identical to SM
    - We all can do MVA's… we would need something based on physics and not data analytics

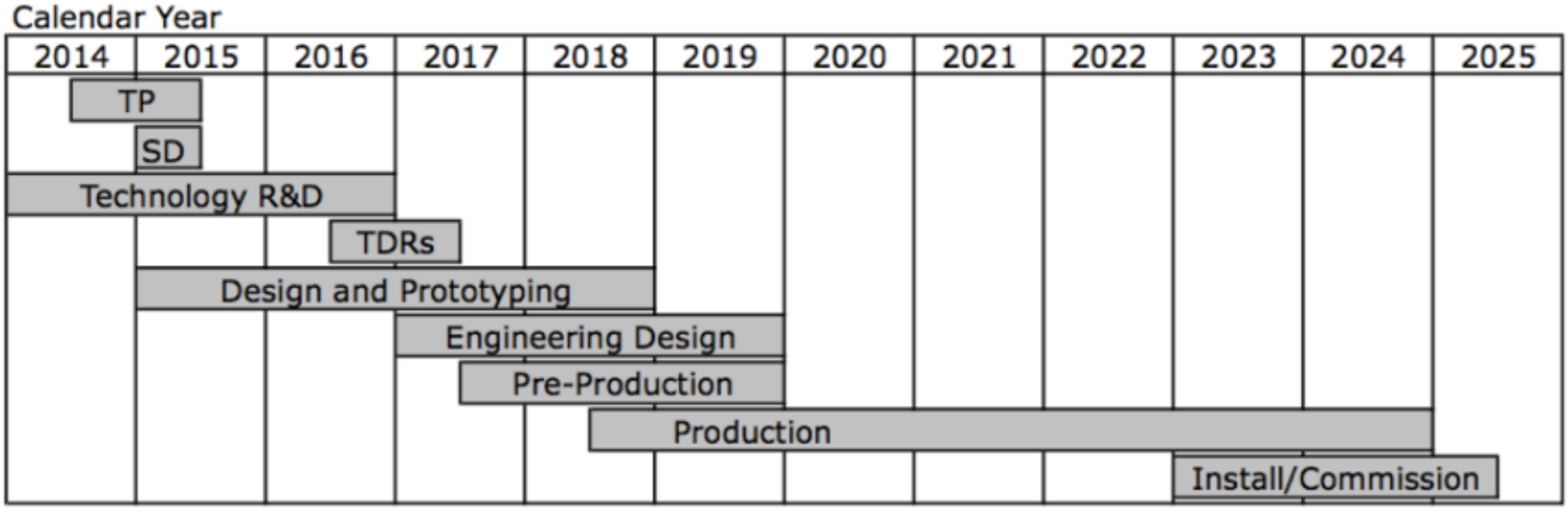
Scenarios for Tracking

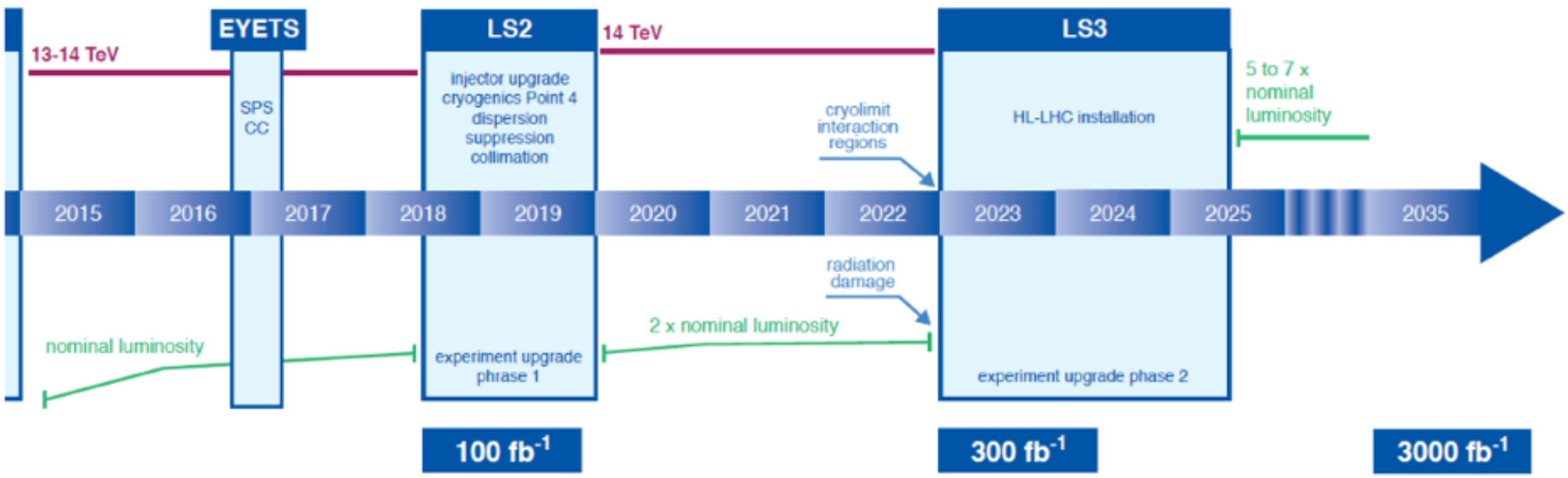
- **Scenario 3 : No new physics hints after 1000 fb-1?**
  - Ugh.
  - Higgs portals? Twin Higgs? Turtles all the way down?

  - For the tracker :
    - Critical H->invisible with VBF modes —> critical to have extended tracker coverage
    - Plus everything from before

  - Theory inputs :
    - Calculations, calculations, calculations
    - Need precision calculations to compare to precision measurements
    - Rethinking symmetry? Big ideas?

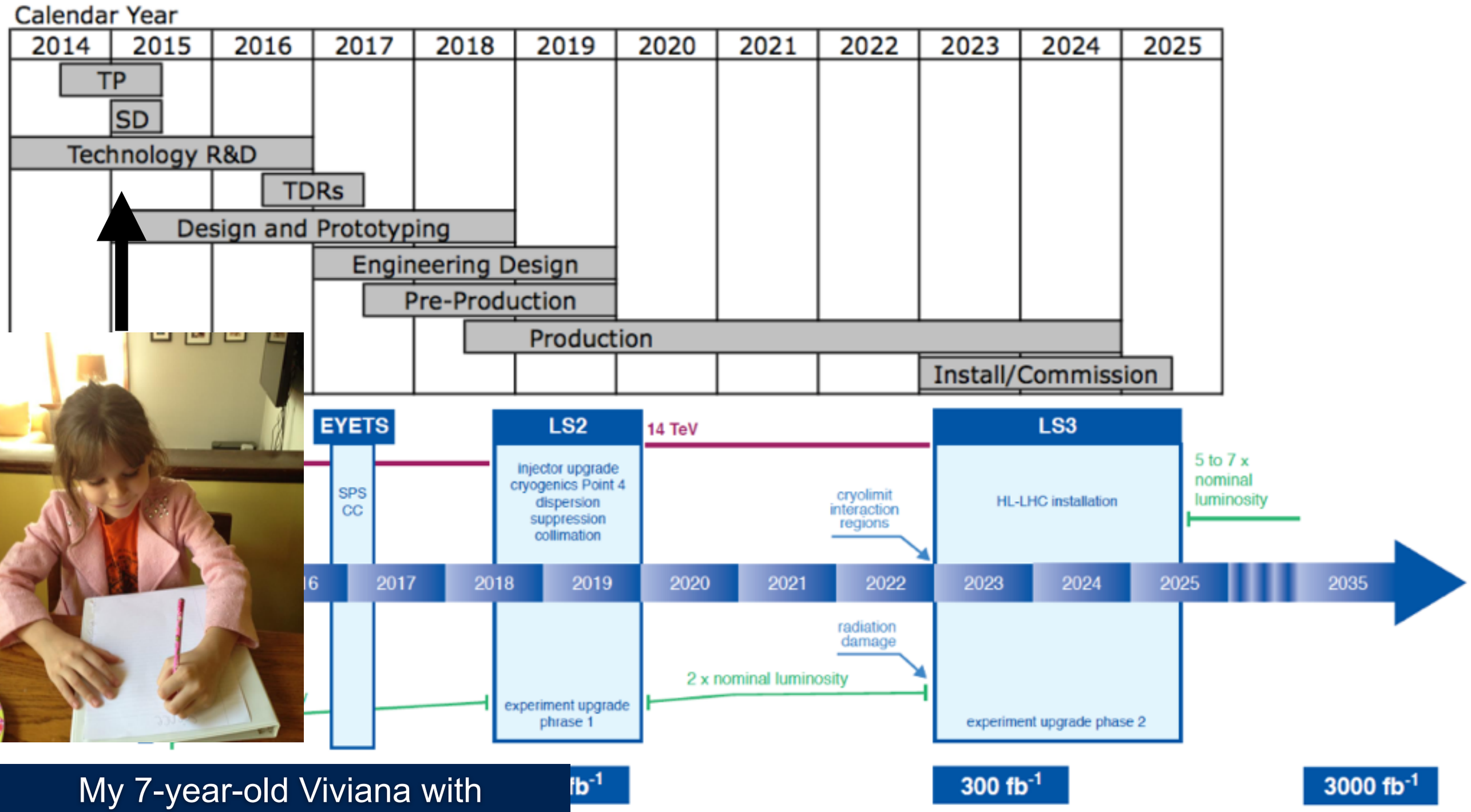
HL-LHC Tracker Timeline





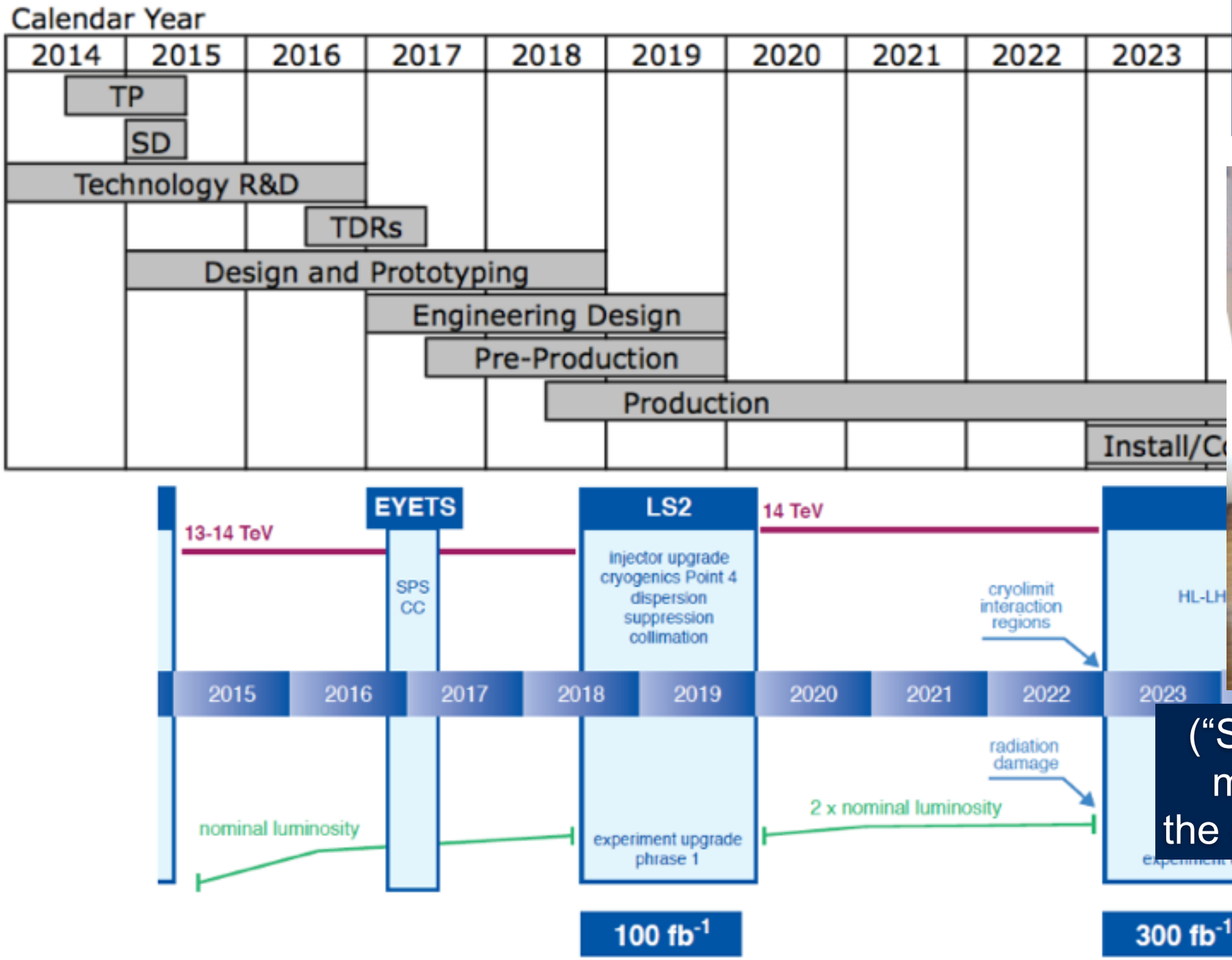
Slide from Vivian O'Dell (US CMS meeting)

HL-LHC Tracker Timeline



My 7-year-old Viviana with ideas for the Phase 2 upgrades : ("we need a new color scheme, and more integrated PF capabilities")

HL-LHC Tracker Timeline



She'll be looking for faculty positions when we have 3000 fb-1

("See? I told you we needed more PF capabilities. And the color scheme looks great!")