The "Phase 1" Upgrade of the CMS Silicon Pixel Detector

Carlotta Favaro,
University of Zurich

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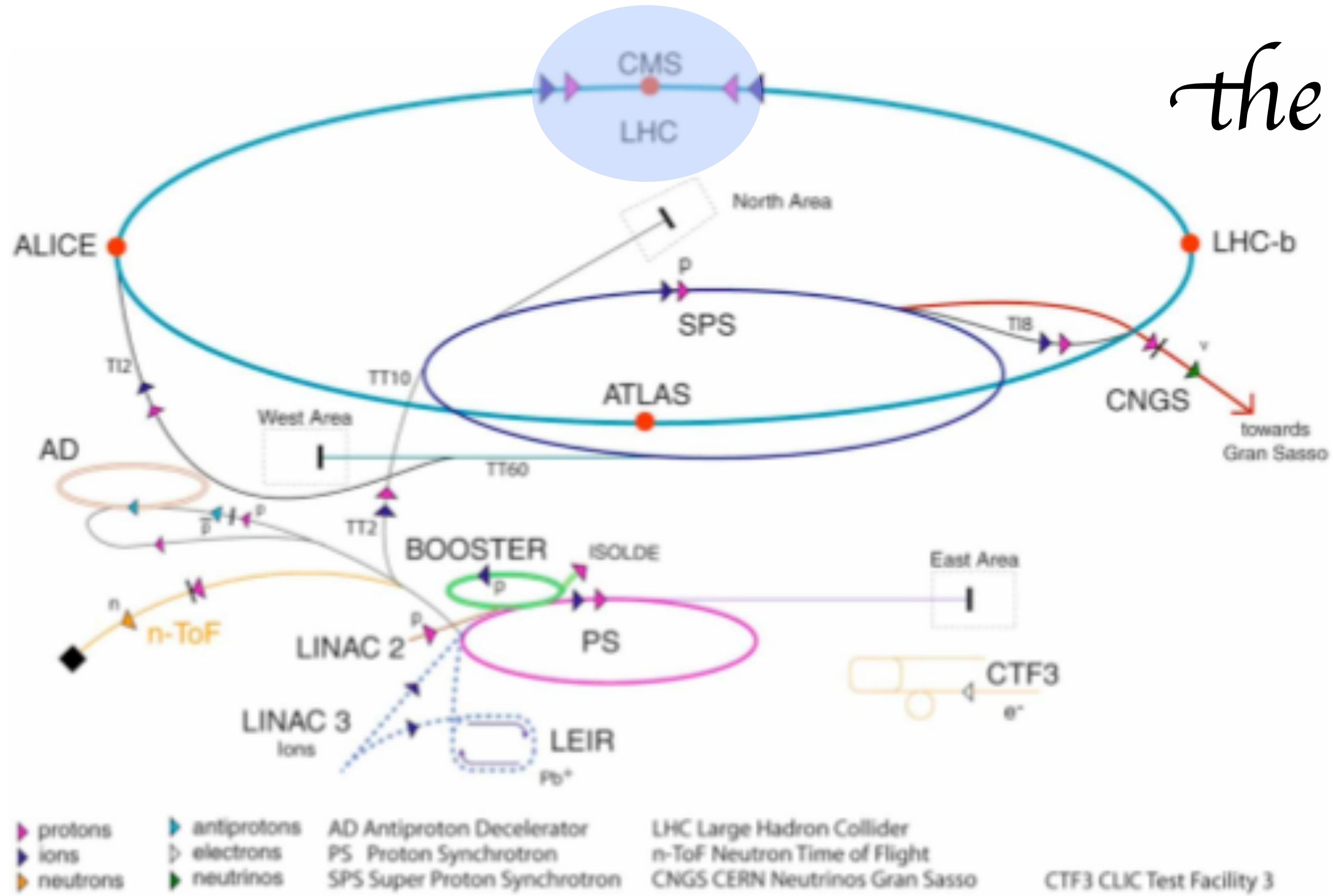
Talk Outline

- Brief description of the Large Hadron Collider at CERN
- The Compact Muon Solenoid installed at Point5
- Current layout of the silicon pixel detector
- Schedule of the LHC machine operation and planned upgrades
- "Phase1" upgrade of the silicon pixel detector:
  - reasons why it's required
  - new detector design
- Simulation study of the new detector performances.

the Large Hadron Collider



After the successful run of December 2009 the world's highest energy collider:

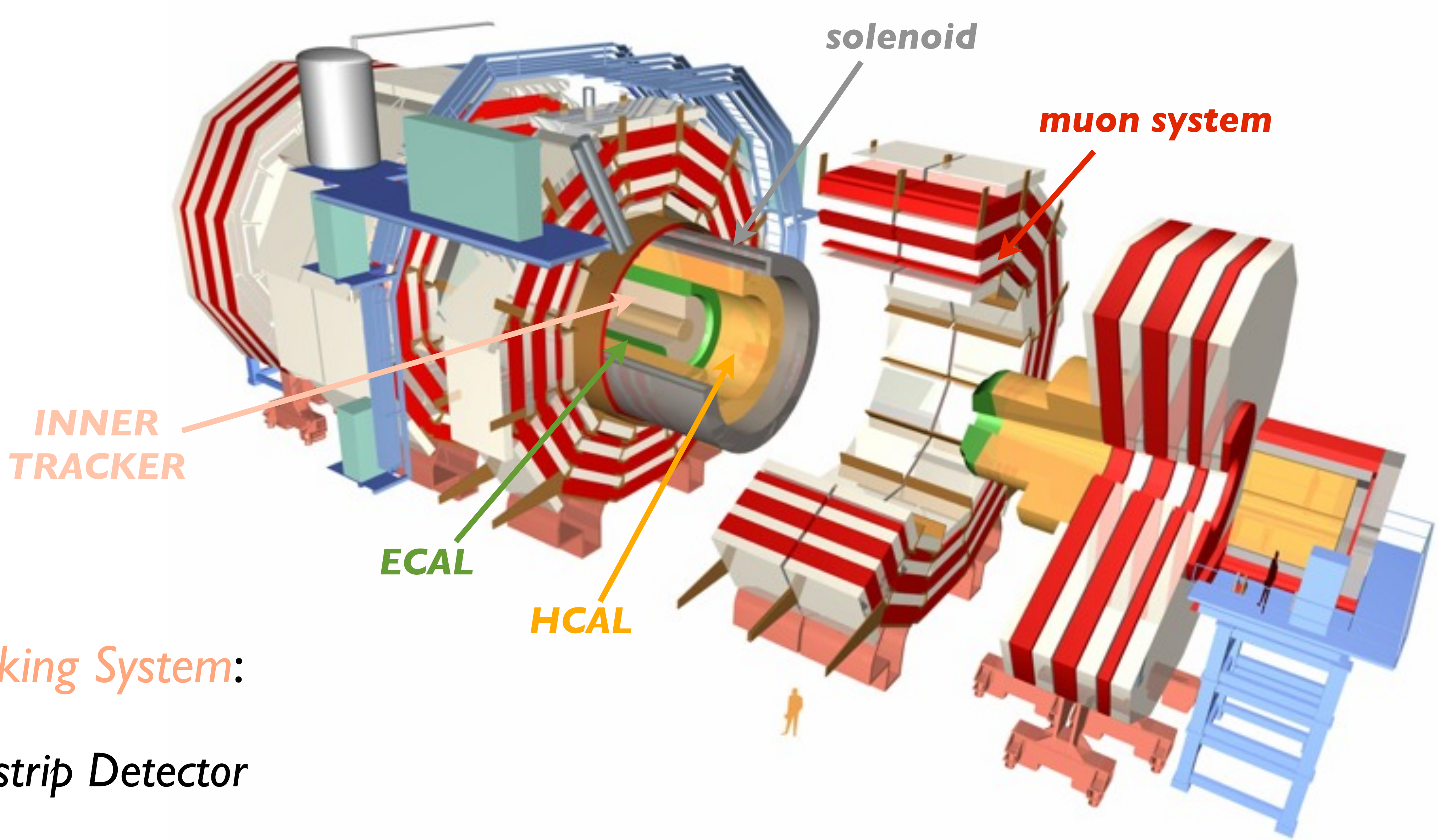
$\sqrt{s}$ = 2.36 TeV !

- two beam pipes intersecting where experiments are installed
- superconducting magnets to bend and focus
- radiofrequency cavities to accelerate the beams
- preacceleration facilities (LINAC 2, PSB, PS and SPS) before injection.

Relevant machine parameters:

- center-of-mass energy $\sqrt{s}$ = 14 TeV
- design luminosity $\mathcal{L}$ = 10^{34} cm^{-2} s^{-1}
- bunch structure: bunch separation $\Delta\tau_b$ = 25 ns
- number of protons/bunch N_p = 1.15×10^{11}

the Compact Muon Solenoid



- Silicon Tracking System:
- *Silicon Microstrip Detector*
- *Silicon Pixel Detector* close to interaction region:
  - high occupancy of detector channels
  - exposure to high particle fluences.

$\mathcal{L}$HC schedule - upgrades

$\mathcal{L}$HC

- successful start up in end 2009
- 3-4 years of operation at design luminosity (200fb^{-1} expected)
- $\mathcal{L} = 10^{34}$ cm^{-2} s^{-1}

$\mathcal{L}$HC "Phase 1"

- planned for ~2015
- ~5 years of operation at design luminosity
- minor changes: substitution of the LINAC, upgrade of collimation system at the interaction regions
- $\mathcal{L} = 2 \times 10^{34}$ cm^{-2} s^{-1}

Super $\mathcal{L}$HC

- still under evaluation: planned for ~2019
- major changes: pre-acceleration and injection and collimation at interaction regions
- $\mathcal{L} = 10^{35}$ cm^{-2} s^{-1}

CMS Detector:

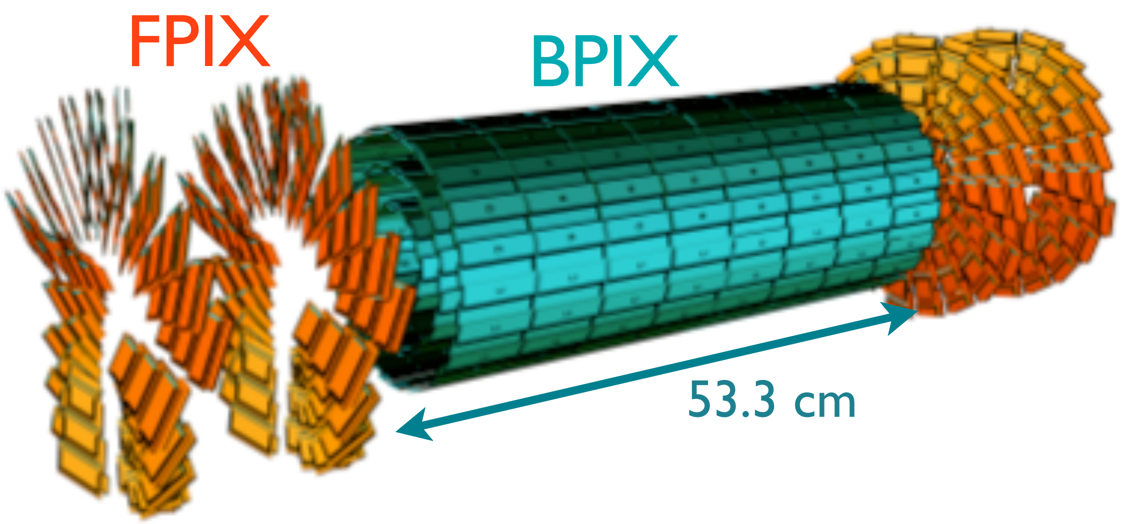
$\mathcal{L}$HC "Phase 1":

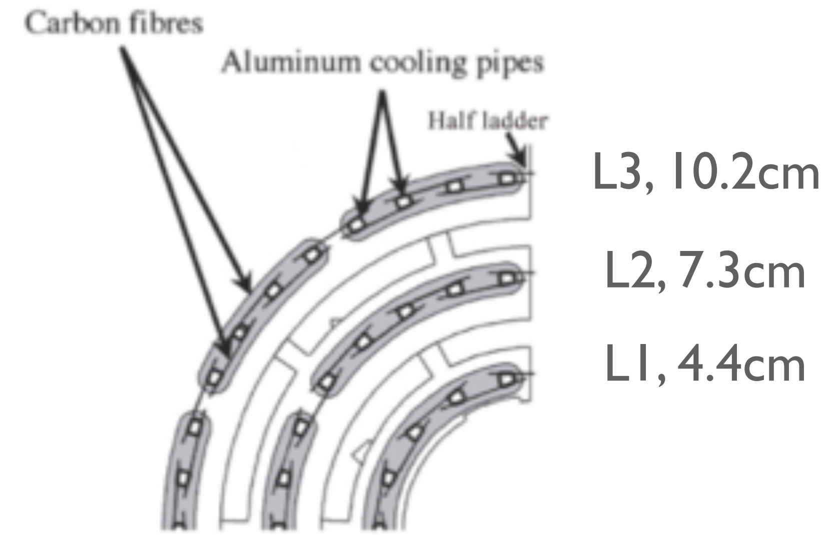
- substitution and upgrade of the *silicon pixel detector*

Super $\mathcal{L}$HC:

- complete substitution and upgrade of the *tracker*
- minor changes to calorimetry and muon system
- redesign of *trigger* and *data acquisition systems.*

the current CMS Pixel Detector





- two endcap disks with turbine-like geometry (*FPIX*)
- three concentrical barrel layers (*BPIX*):
- composed of modular detector units (*modules*)
  - 8 modules placed on a mechanical structure of carbon fiber supports (*ladders*) attached to aluminium cooling pipes circulating liquid Fluorocarbon ($C_6 F_{14}$)
  - each module made of 8 to 16 segmented silicon sensors
    - each composed by a 52 x 80 array of
    - 150μm x 100μm pixels
  - with highly integrated read-out chips (*ROCs*).

Pixel Upgrade: why?

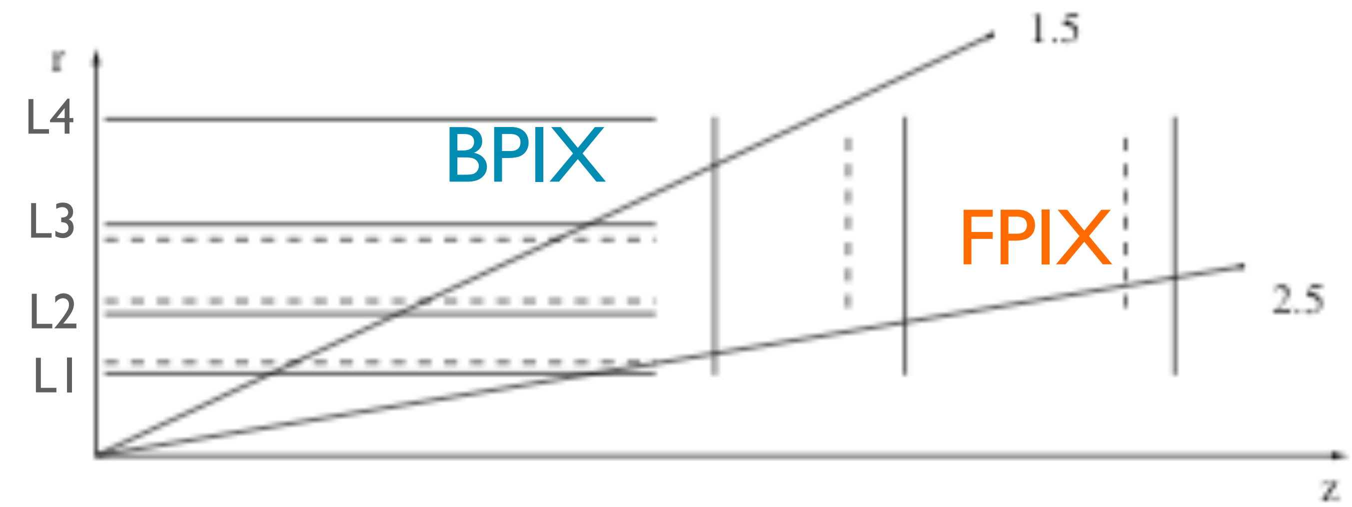
A. Radiation damage:

1. surface and bulk defects in the silicon lattice
2. modification of charge density and drift field, trapping of charge carriers, decrease of average collected charge
3. increase the bias voltage to compensate the charge loss
4. degradation of detector performances: *Efficiency* and *Resolution.*

B. Need to maintain good detector performances despite high sampling rates and large number of pile-up events:

- higher occupancy of detector channels.

Phase 1 Pixel Detector design



- FPIX: *3 disks* in each endcap

  BPIX: *4 layers* at radii 4, 7, 11 and 16 cm.

- higher *pixel granularity* (still to be evaluated).

- reduction of *material budget* (by a factor of 3 in some regions) to limit the multiple-scattering effect deteriorating position resolution:

  - support structure

  - signal and power cables (moved outside the barrel acceptance)

  - cooling (redesign of the cooling circuit allowed by the use of CO_2).

systematic MonteCarlo simulation studies are needed to define the ultimate detector geometry.

A closer look at Pixel Granularity

Pixel pitch determined by the readout electronics technology:

- now standard 0.25μm CMOS
- could switch to better technology (0.13μm) to decrease read-out cell size
- possible scenarios still under evaluation.

Advantages of higher detector granularity:

- lower occupancy of detector channels
- better position resolution

BUT not obvious! lower limit on position resolution fixed by the multiple-scattering effect (especially for low-p_T tracks).

Detailed simulation study required to evaluate whether the improvement is worth the effort!

Study of detector performances:

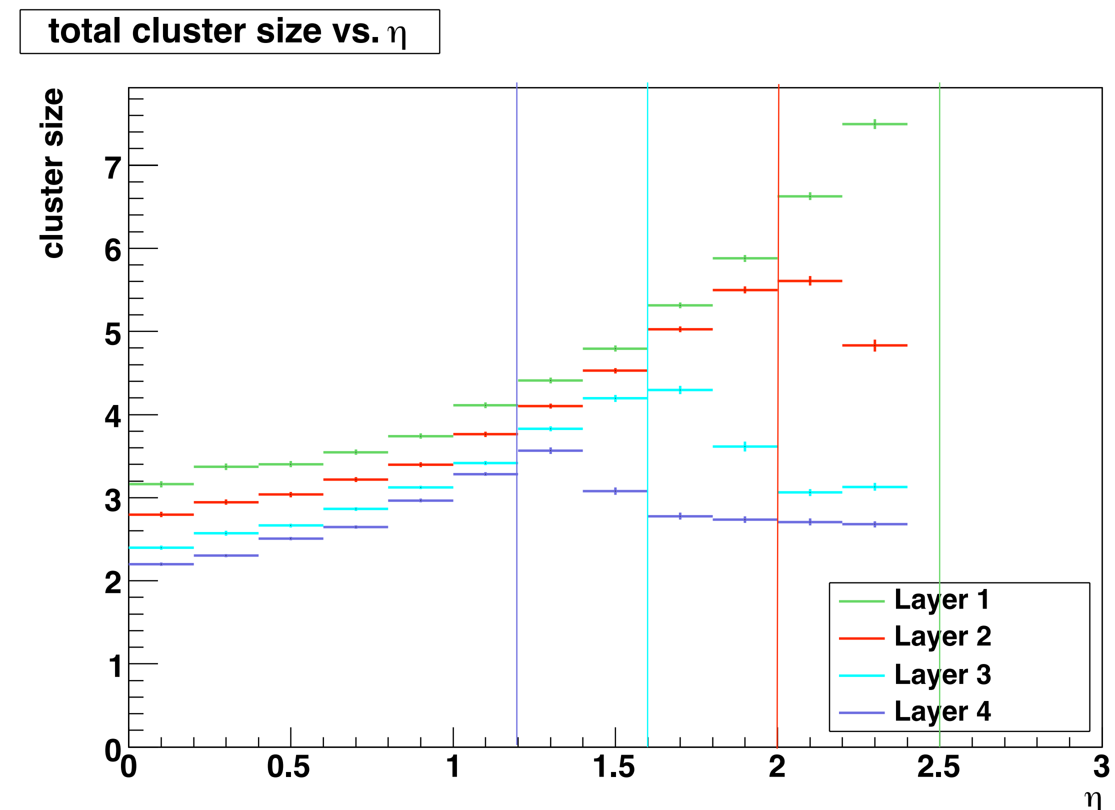
- detector occupancy
- cluster size: number of pixels within a cluster
- position resolution
- resolution of track parameters (measured specifically by the Pixel Detector)
- track reconstruction efficiency.

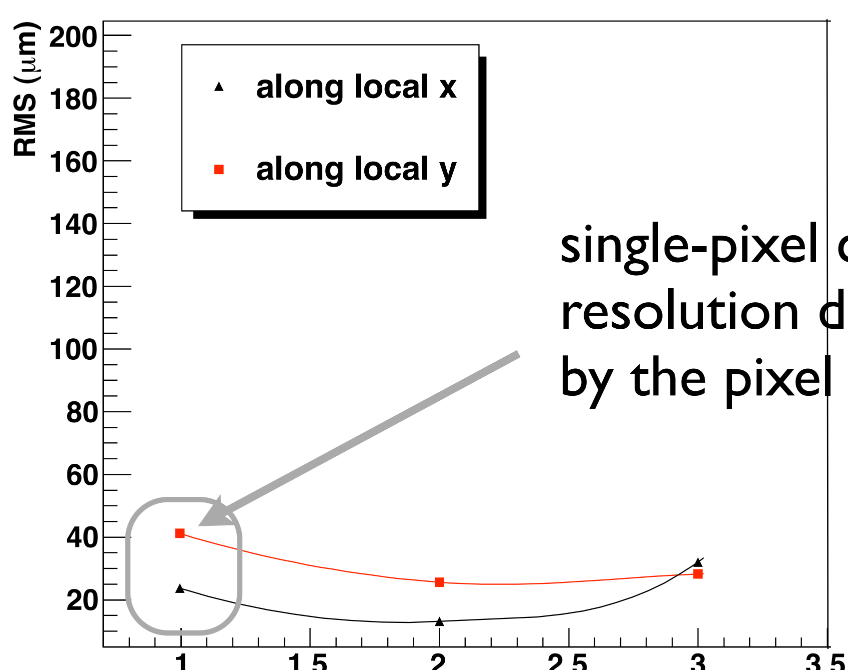
Very Preliminary results:

- from Monte Carlo sample of muons (flat p_T and η distributions)...need to repeat the study on a sample from proton collisions (QCD events with pile-up, b-jets...)!
- Full simulation
- with current detector granularity.

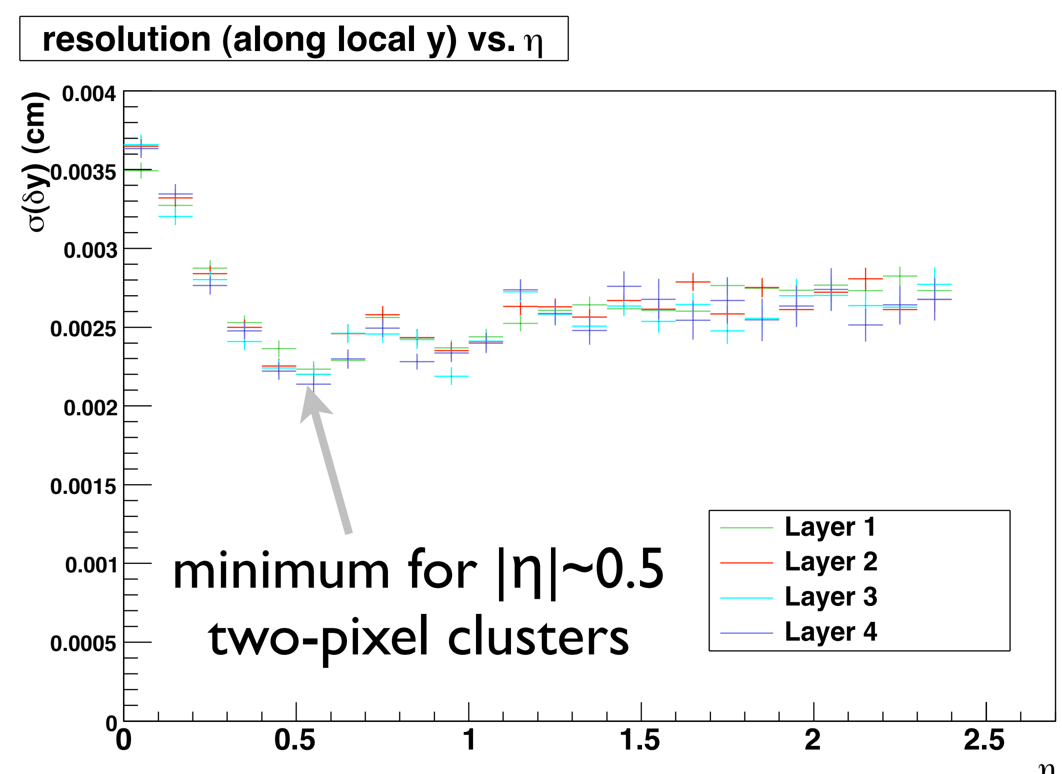
Position Resolution and Cluster Size

local module coordinates: {
- x in transverse plane
- y along beams





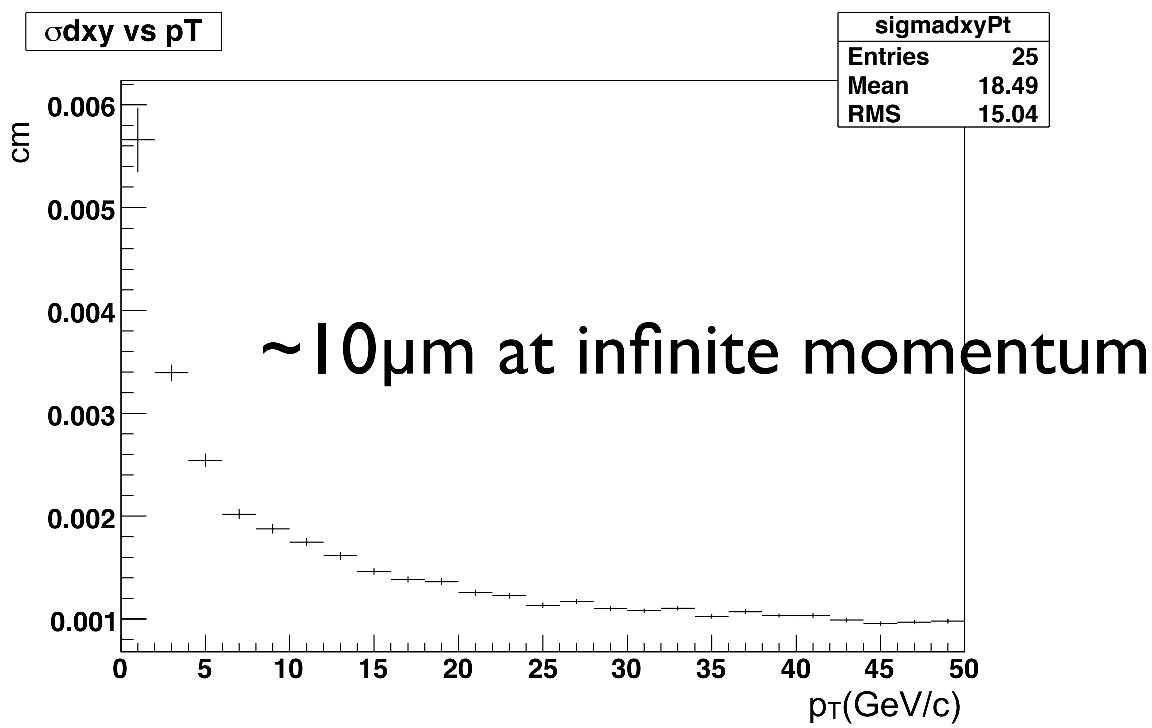
single-pixel clusters: resolution determined by the pixel pitch

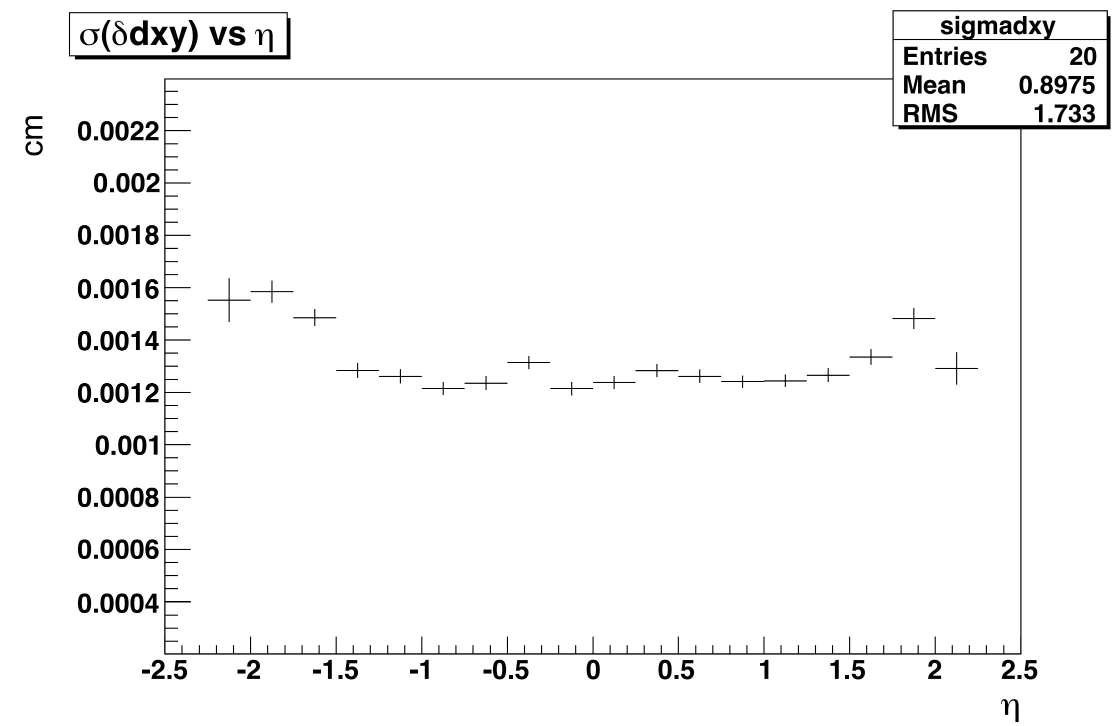


minimum for |η|~0.5 two-pixel clusters

Track Parameters Resolution (i)

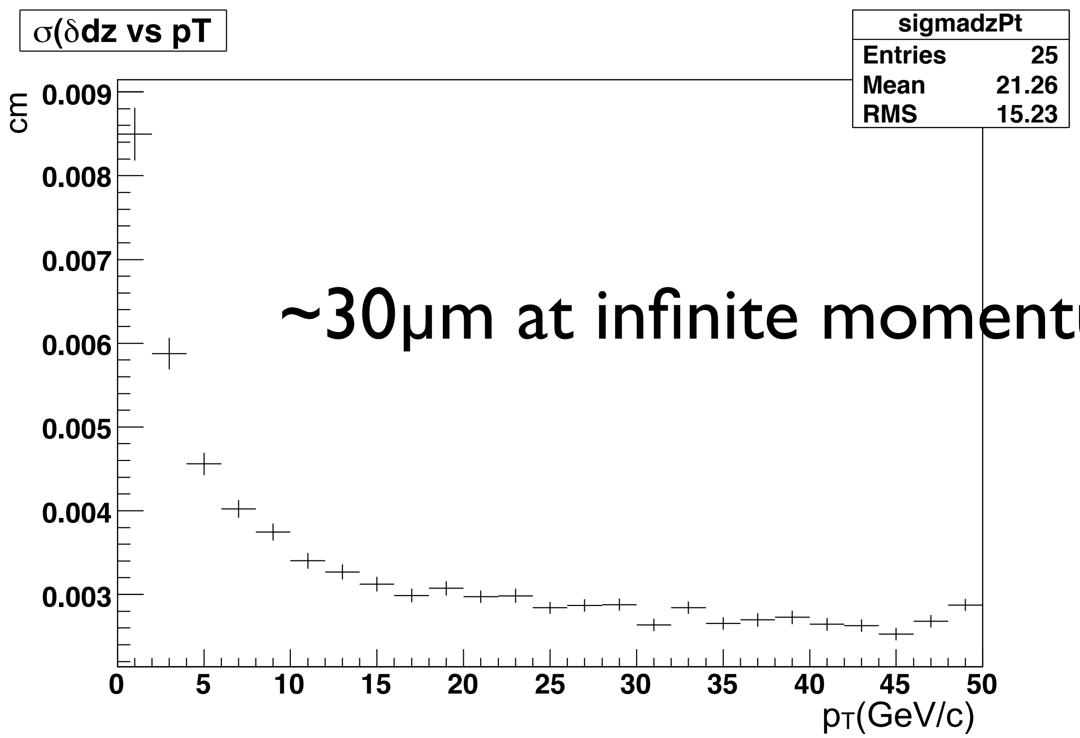
Four out of the Five track parameters are measured by the Pixel Detector: impact parameter (transverse dxy and longitudinal dz) and angles (ϕ and cot(θ))



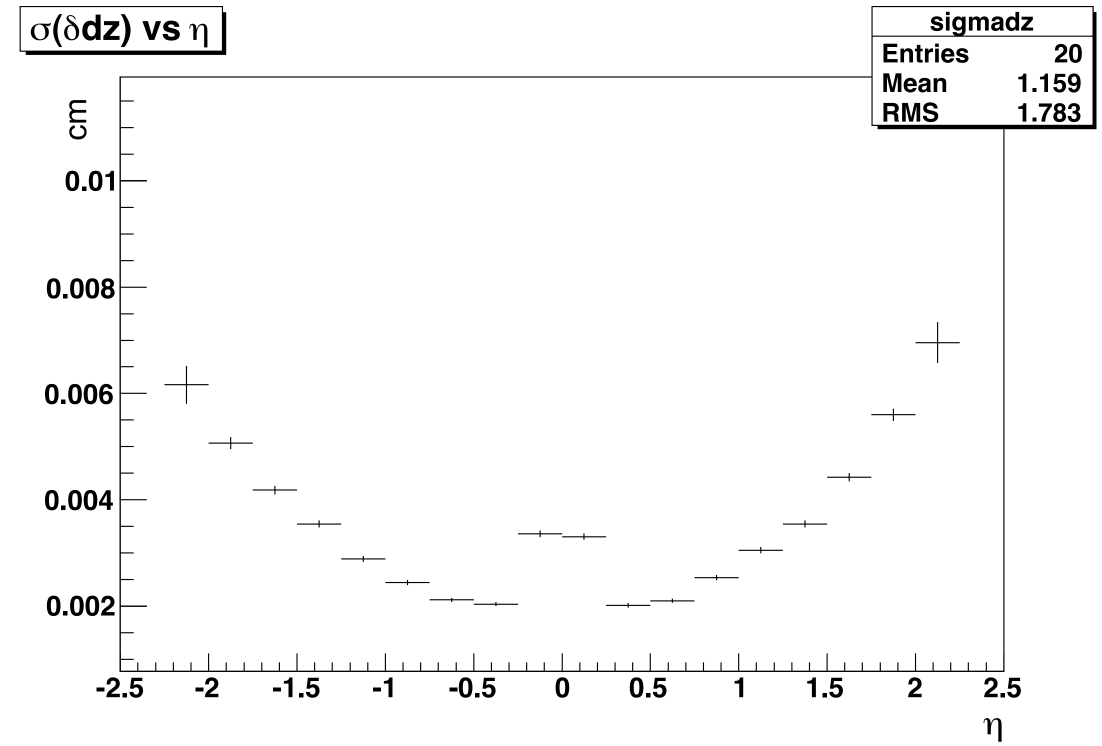


- Transverse Parameters (dxy, ϕ):
  - flat in η
  - higher for low-p_T tracks, due to multiple scattering.

Track Parameters Resolution (ii)



~30μm at infinite momentum



- Longitudinal Parameters (dz, cot(θ)):
  - minimum for |η| ~ 0.5 (two-pixels clusters)
  - higher for low-p_T tracks, due to multiple scattering.

Summary

- After 3-4 years of LHC operating at design luminosity the substitution and the upgrade of the Silicon Pixel Detector at CMS will be necessary, due to:
  - degradation of detector performances by radiation damage
  - need to cope with the higher rates and event complexity resulting by the increased luminosity.
- New detector design needs to be evaluated now with Monte Carlo simulation analysis!
- Next steps:
  - simulate proton collisions Monte Carlo sample
  - study physics performances with smaller pixel cell sizes.