Upgrade plans and ageing studies for the CMS muon system in preparation of HL-LHC

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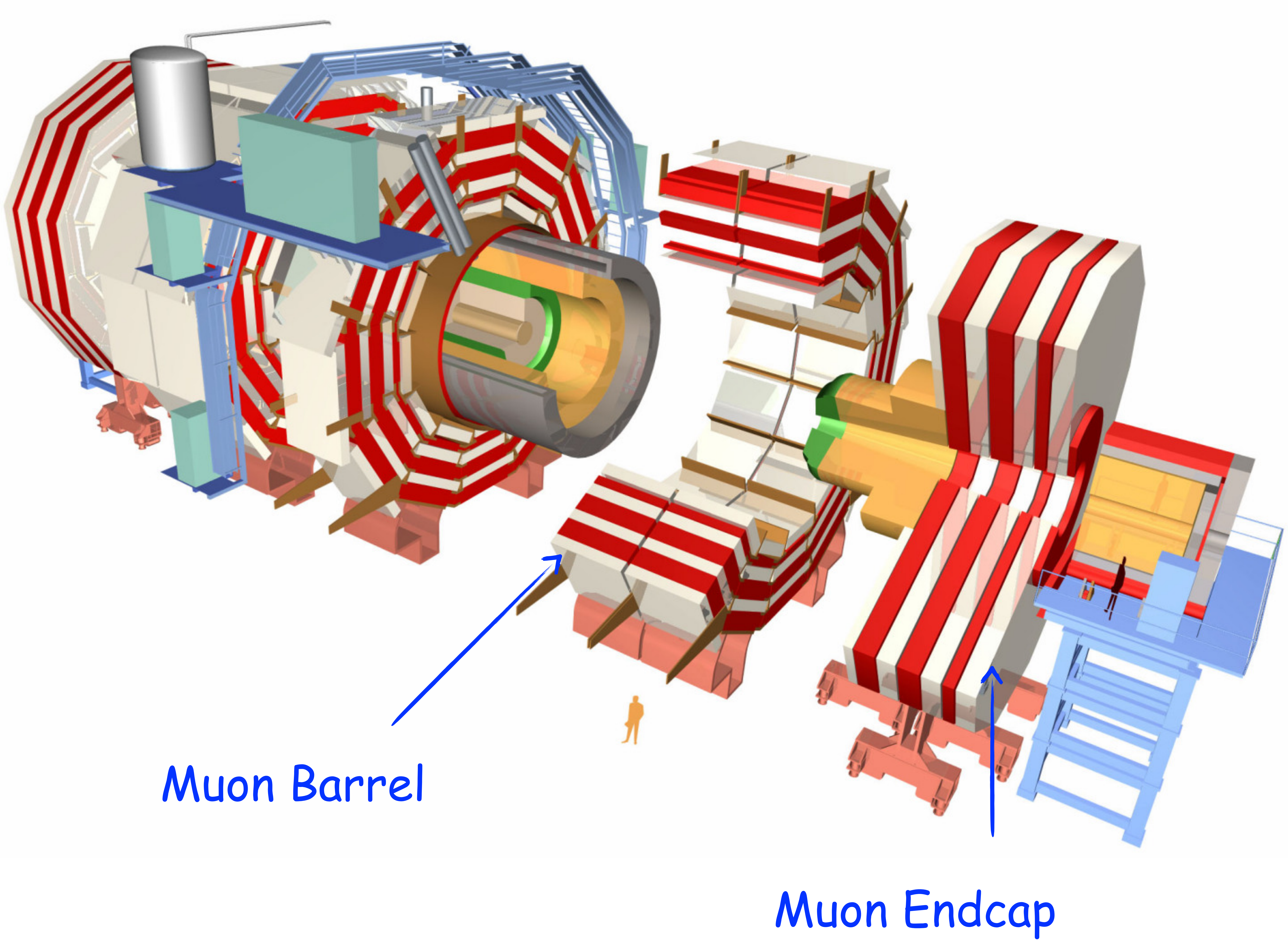
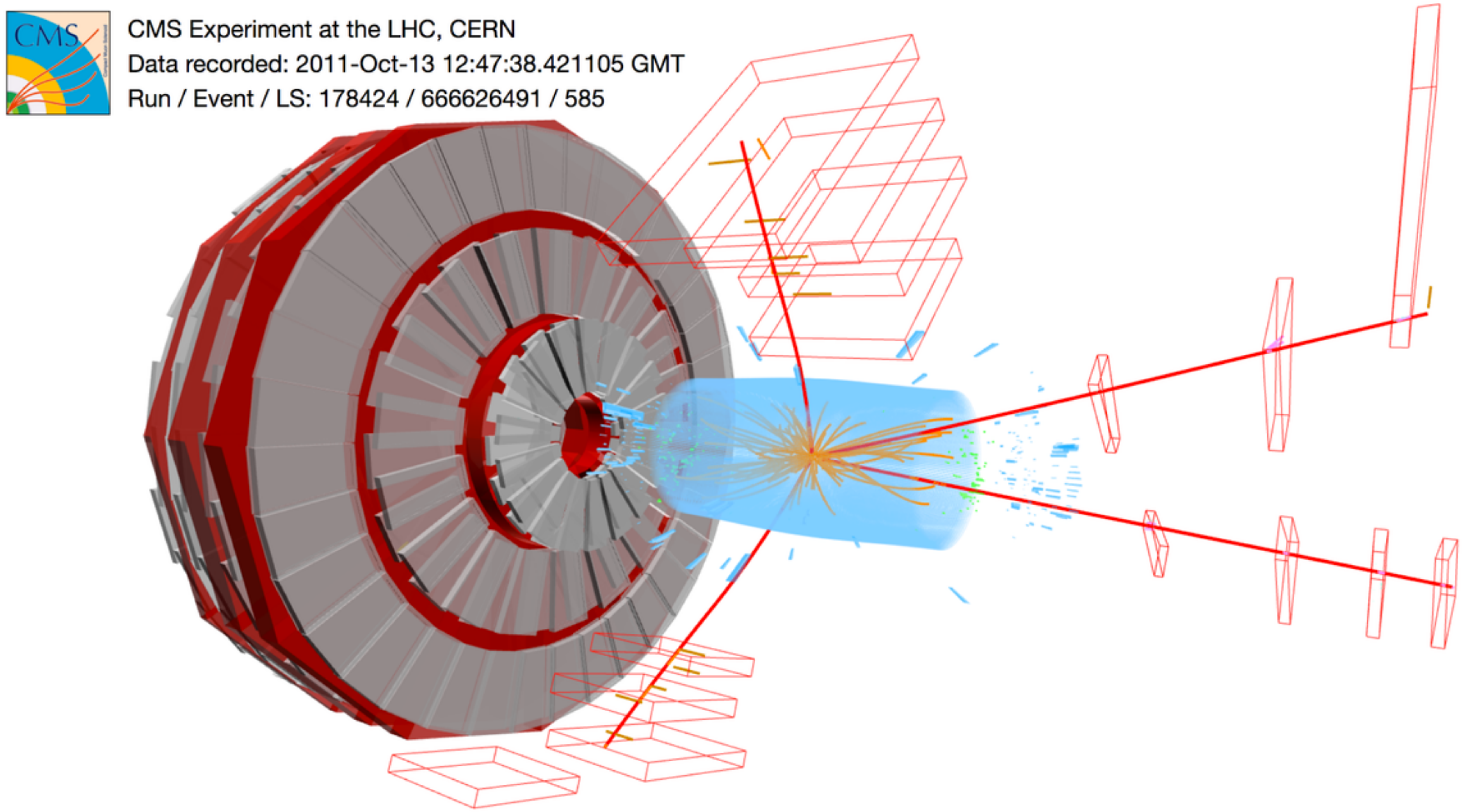
On behalf of the CMS Muon Group

14th Pisa meeting on advanced detectors
June 1st, 2018, La Biodola

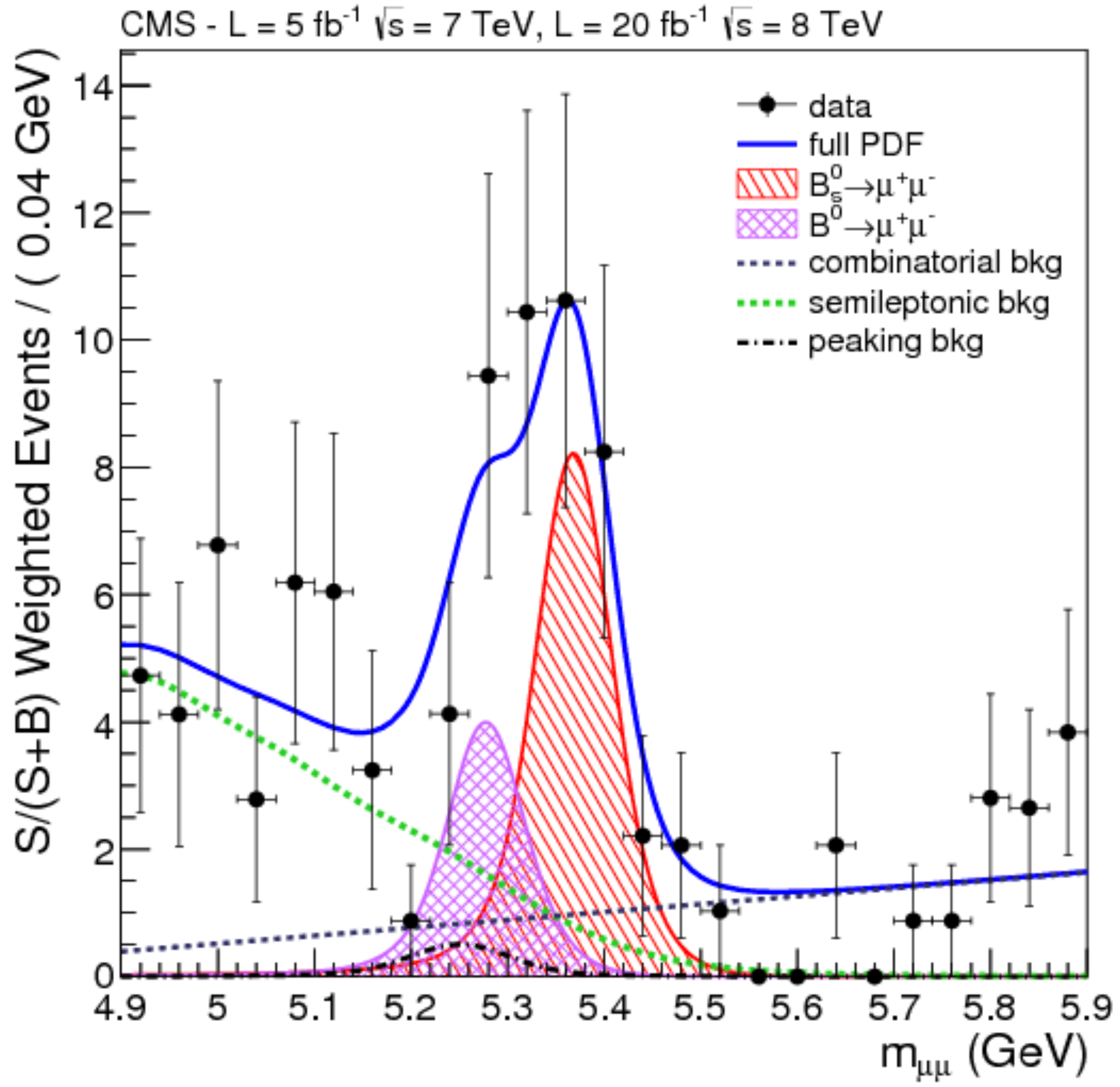


- Hadrons are copiously produced at LHC
- Almost all hadrons, electrons, and photons are absorbed in calorimeters
- Trigger, identification and measurement of muons is of great importance in searching for interesting and rare processes

Higgs -> ZZ -> 4μ
The golden channel



Bs -> 2μ rare decay



The present CMS Muon system

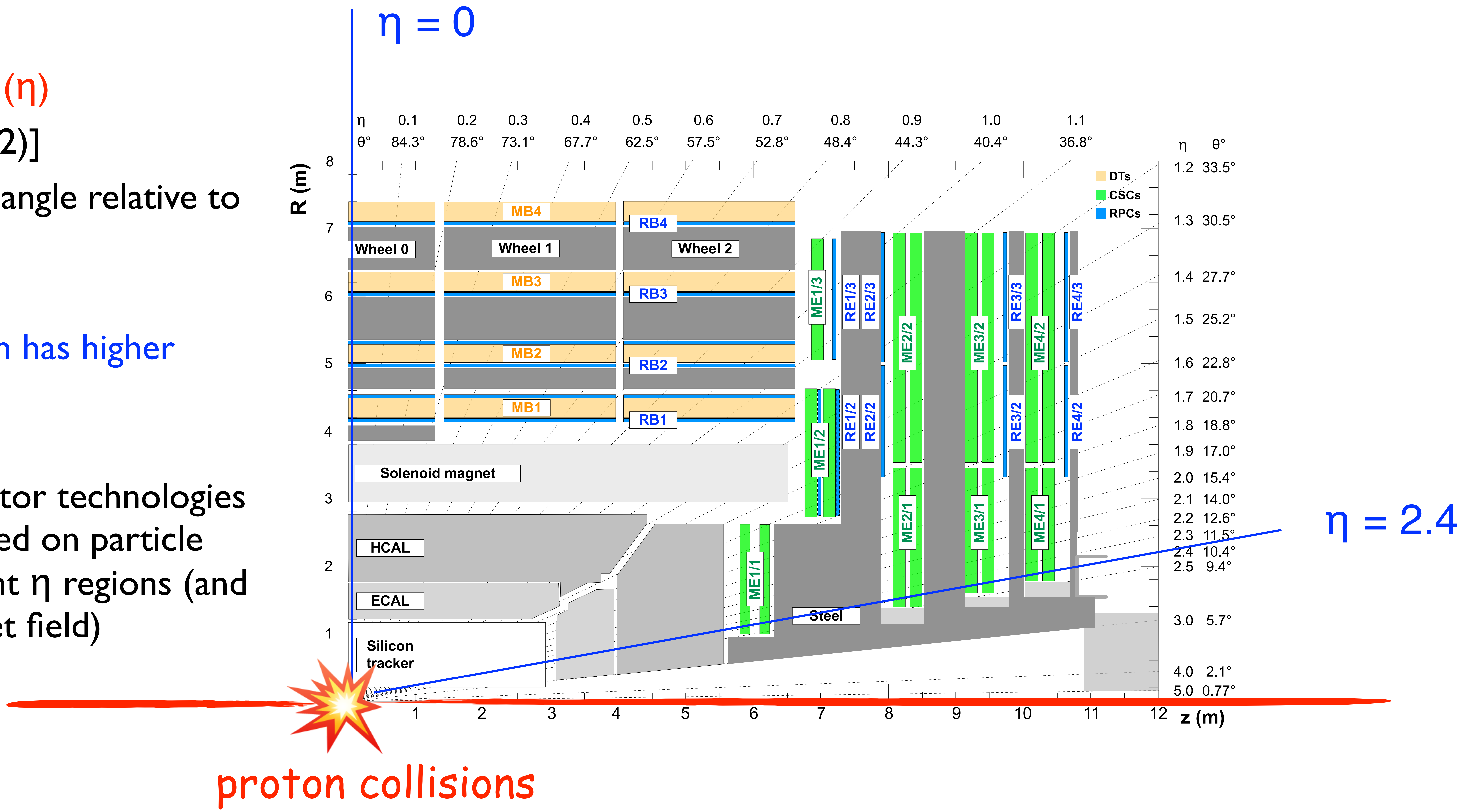
Pseudorapidity (η)

$\eta = -\ln[\tan(\theta/2)]$

where θ is the angle relative to the beam axis

Higher η region has higher particle rate

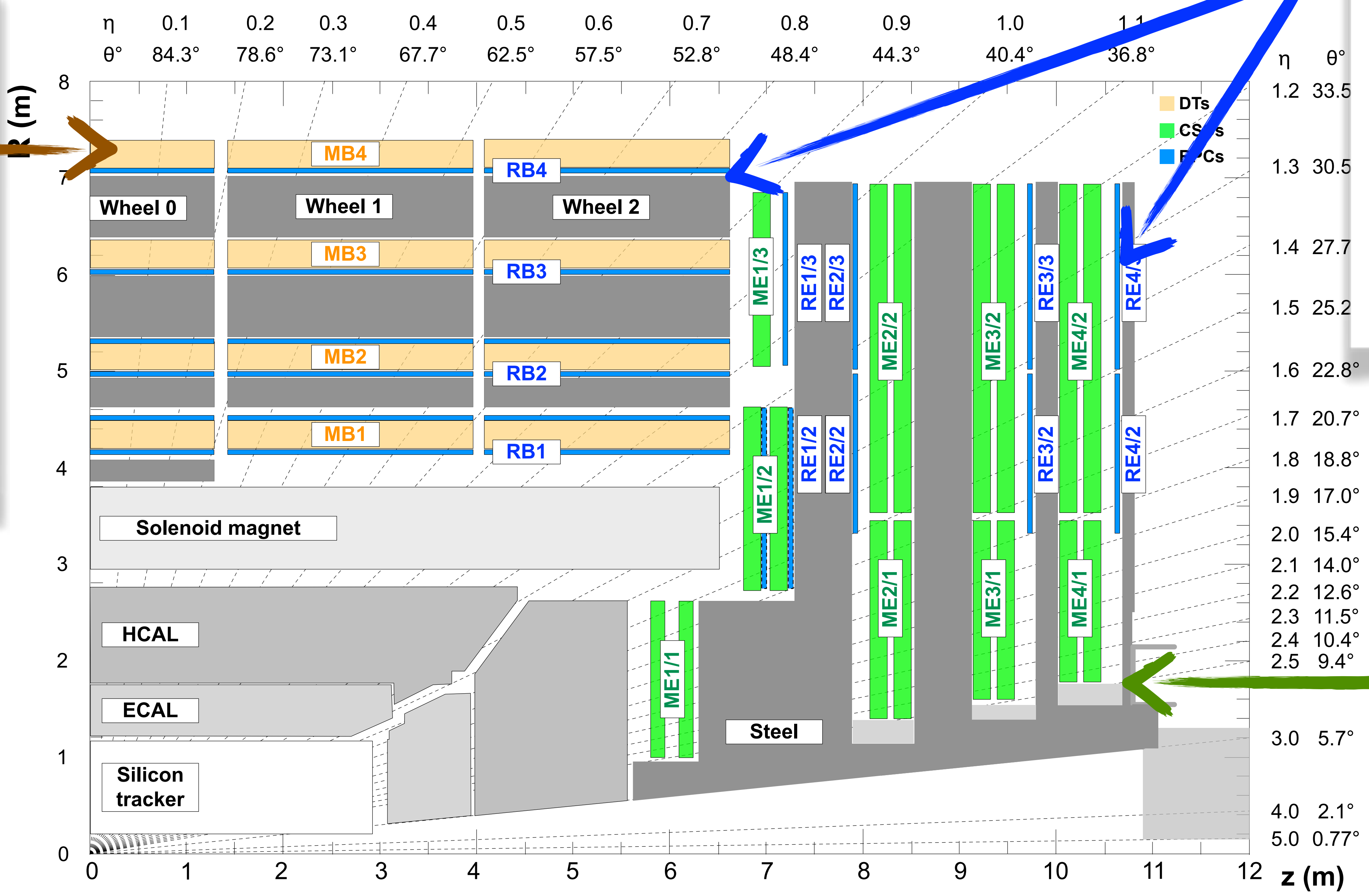
Different detector technologies are chosen based on particle rates in different η regions (and different magnet field)



Three gas detector technologies

Drift Tube (DT):
- $0 < |\eta| < 1.2$
- 250 chambers
- Spatial resolution 100 μm
- Time resolution 2 ns

Low rate



Resistive Plate Chamber (RPC)
- $0 < |\eta| < 1.8$
- 480 (barrel) + 576 (endcap) chambers
- Spatial resolution 0.8-1.3 cm
- Time resolution ~ 2 ns

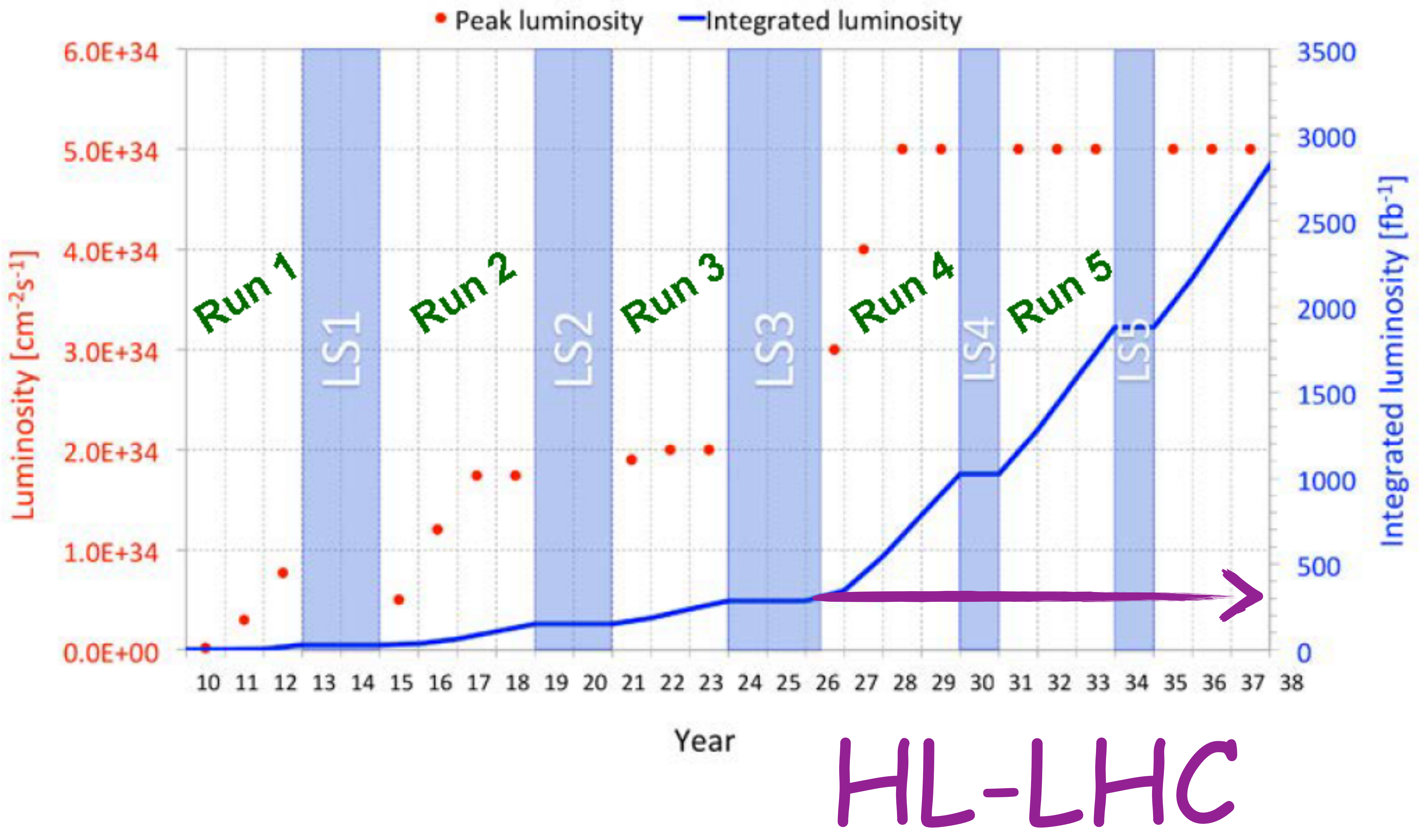
Cathode Strip Chamber (CSC)
- $0.9 < |\eta| < 2.4$
- 540 chambers
- Spatial resolution 50-140 μm
- Time resolution 3 ns

High rate

- *The trajectory of a muon passes 4 stations, 2 types of detectors (except for the high η region)*
- *Robust trigger and efficient reconstruction*

Why upgrade ?

HL-LHC environment defines detector upgrades

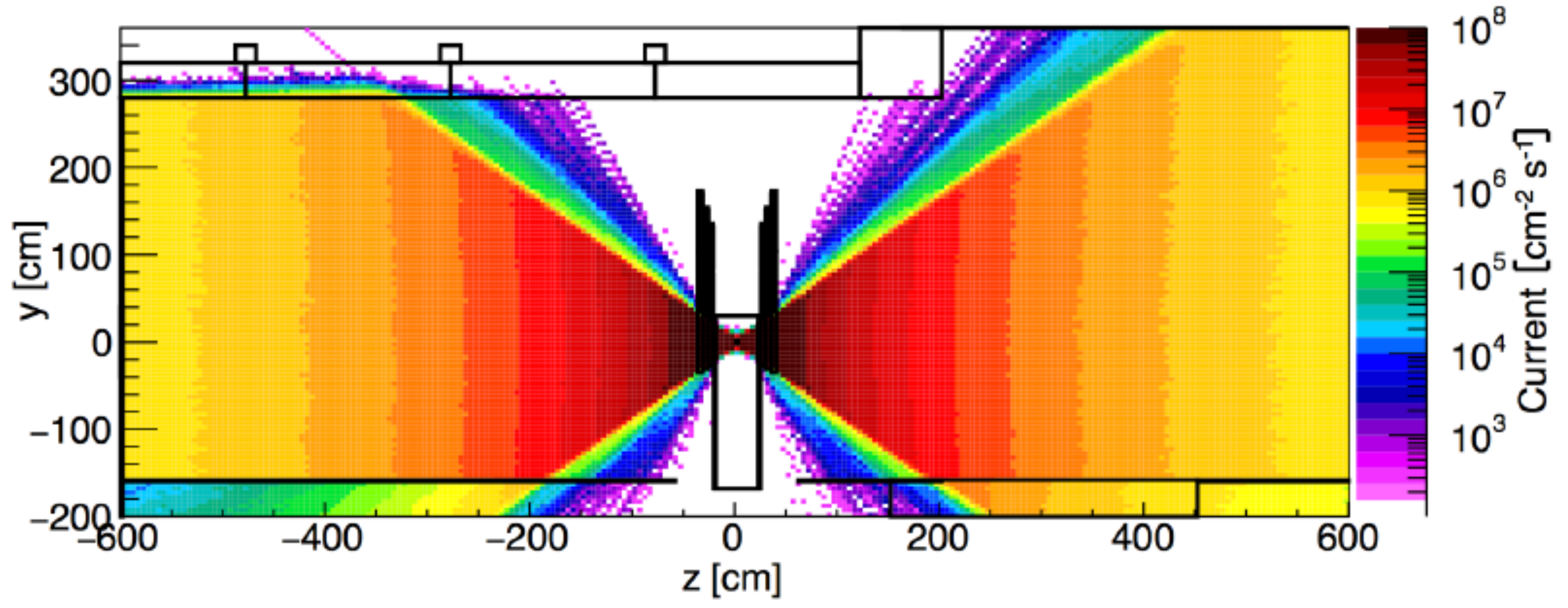


	LHC design	HL-LHC design	HL-LHC ultimate
peak luminosity (10^{34} cm^{-2}s^{-1})	1.0	5.0	7.5
integrated luminosity (fb^{-1})	300	3000	4000
number of pileup events	~30	~140	~200

- CMS detector was designed for the LHC specifications
- Higher integrated luminosity - are the present Muon detectors sufficiently radiation hard?
- Higher instantaneously luminosity - the L1 (hardware) trigger rates 500 kHz and latency 12.5 μs would be too high for the Muon system electronics (100 kHz and 3.5 μs as of today)

Muon detector longevity

- Exposure to HL-LHC radiation could potentially cause detector deterioration and permanent failure
  - Gas gain decrease, spurious hits, self-sustained discharges, HV breakdown
- Full-size DT, CSC, RPC chambers are exposed to high rates at the CERN Gamma Irradiation Facility (GIF++)
  - Accelerated irradiation - accumulated charge per cm of wire or cm2 area is the measure of "radiation exposure"
    - Extrapolated to HL-LHC based on present HV current in CMS as of today
  - In addition, a safety factor of 3 is applied



GIF++ photon flux map
Cs137, 13.5 TBq, 662 keV photons

Muon detector longevity

DT

About 15% of chambers (the ones most exposed to background) are expected to see noticeable gas gain decrease

Muon reconstruction efficiency will remain high, thanks to multiple layers of DT on the path of a muon

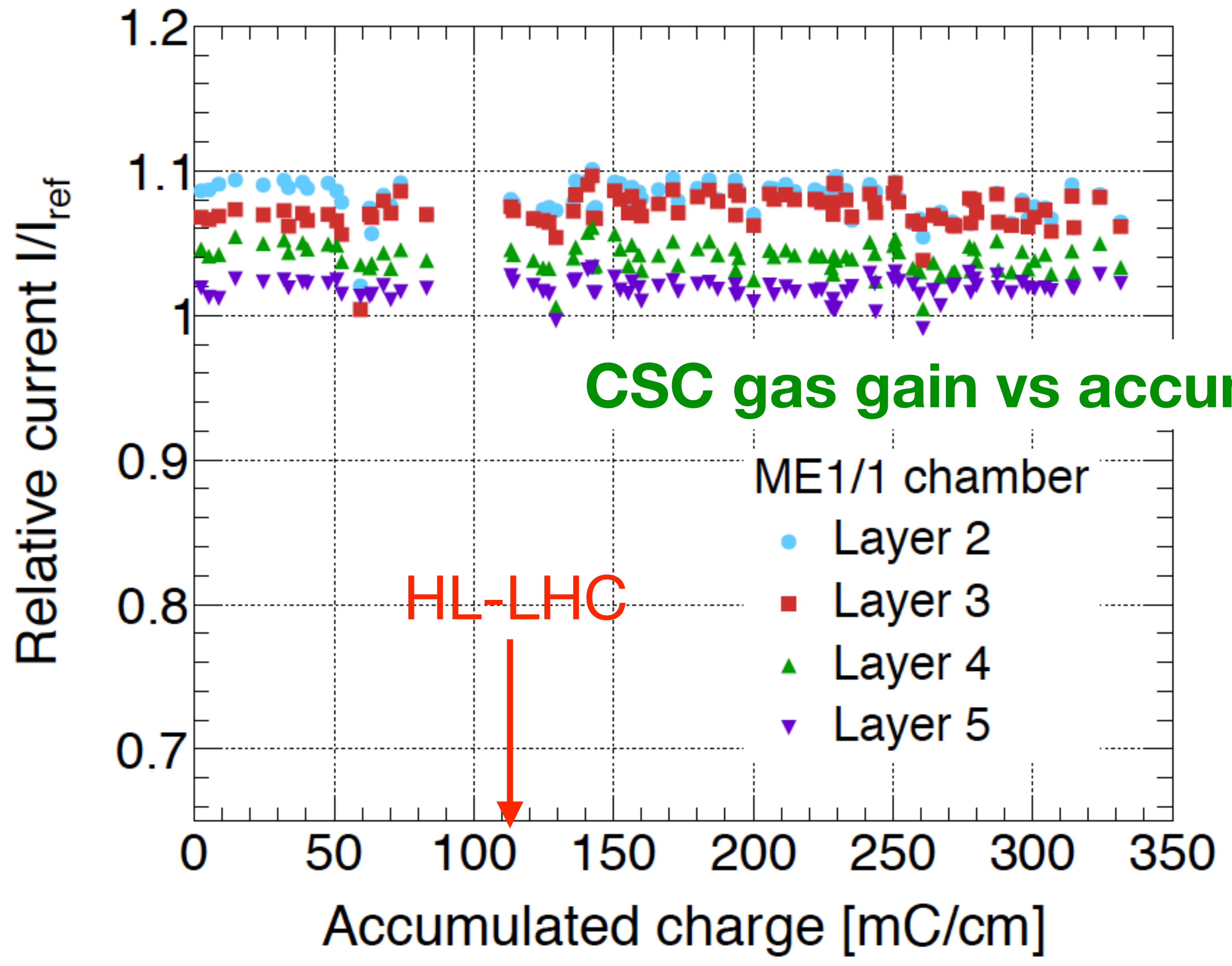
Mitigation measures are being implemented (no gas recirculation, HV adjustment, shielding for chambers, etc)

RPC

No noticeable performance degradation so far (2xHL-LHC); the test is being continued

CSC

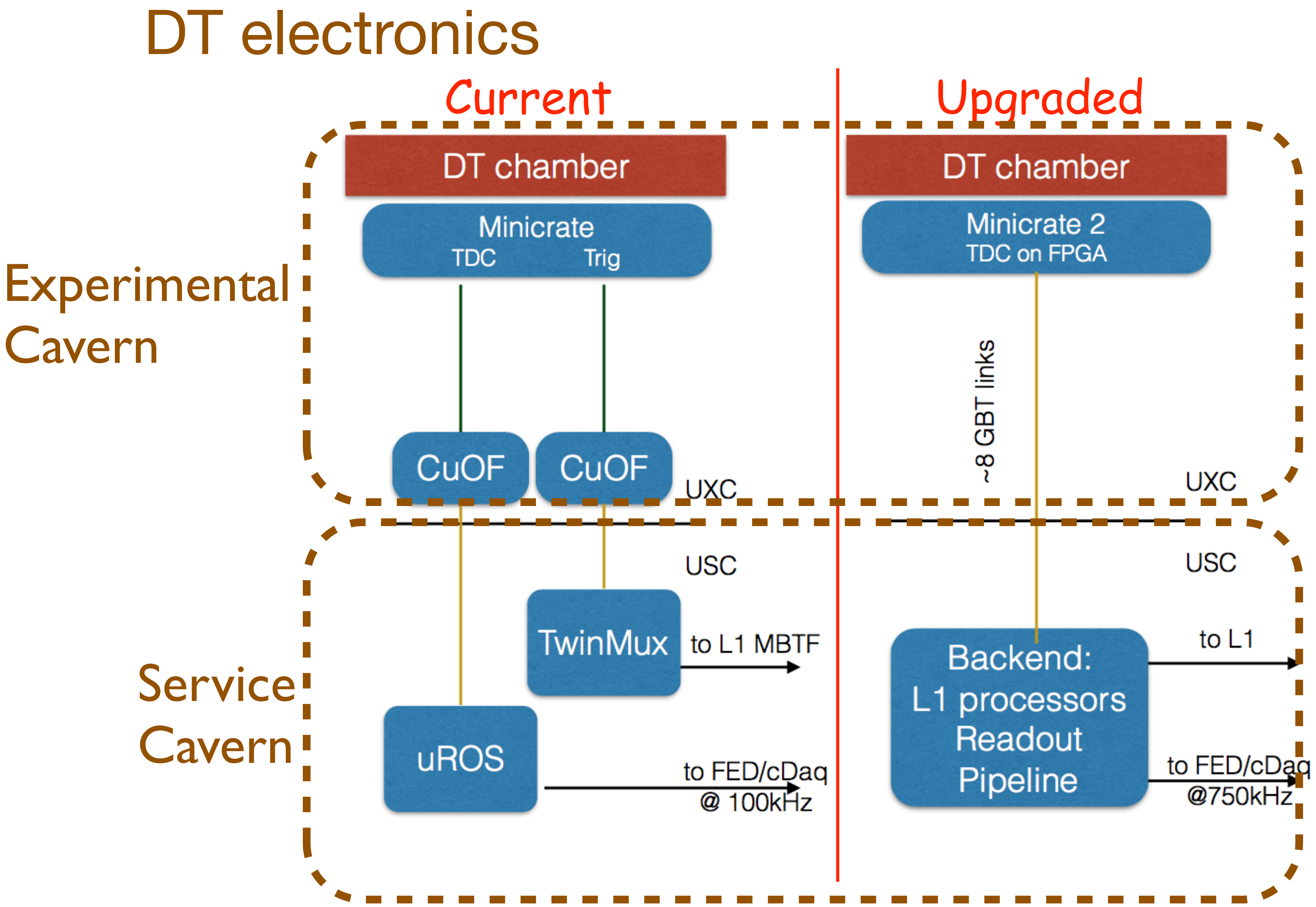
No noticeable performance degradation up to 3 x HL-LHC (330 mC/cm)

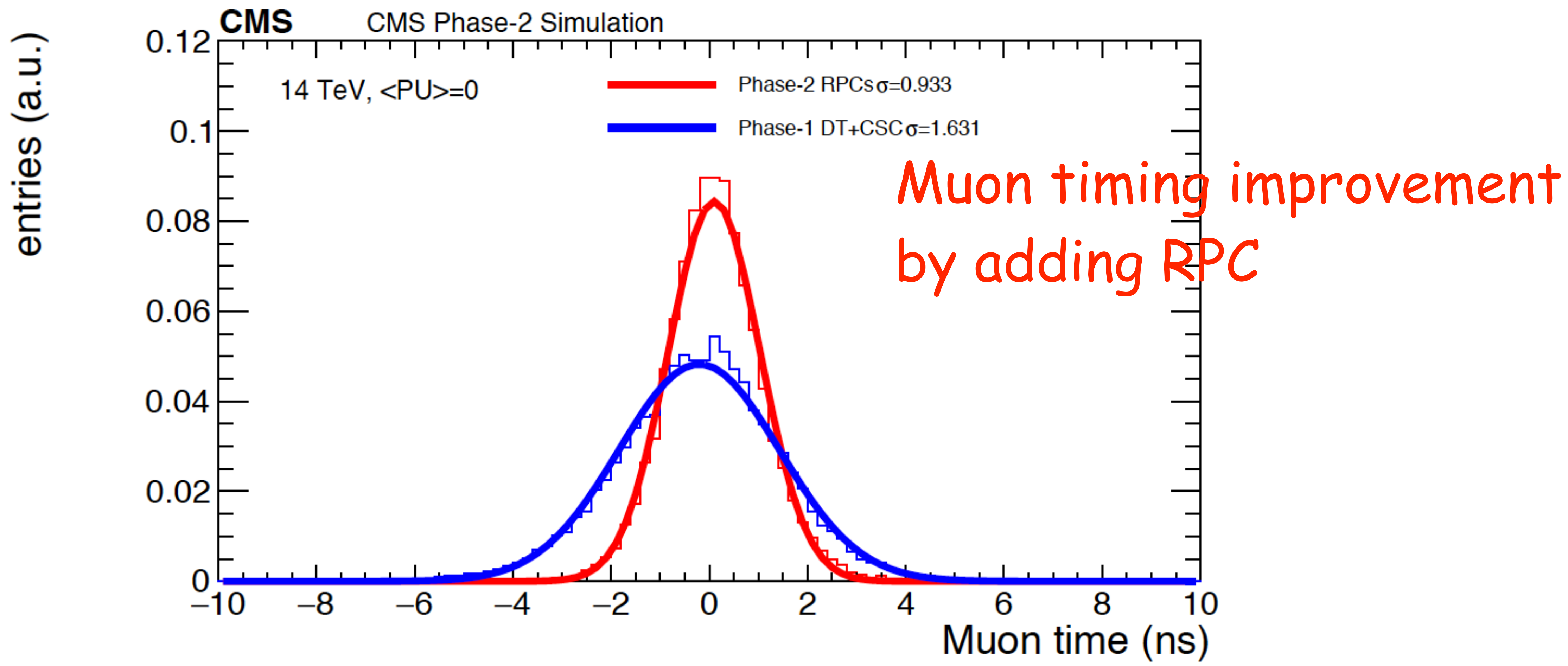


CSC gas gain vs accumulated charge

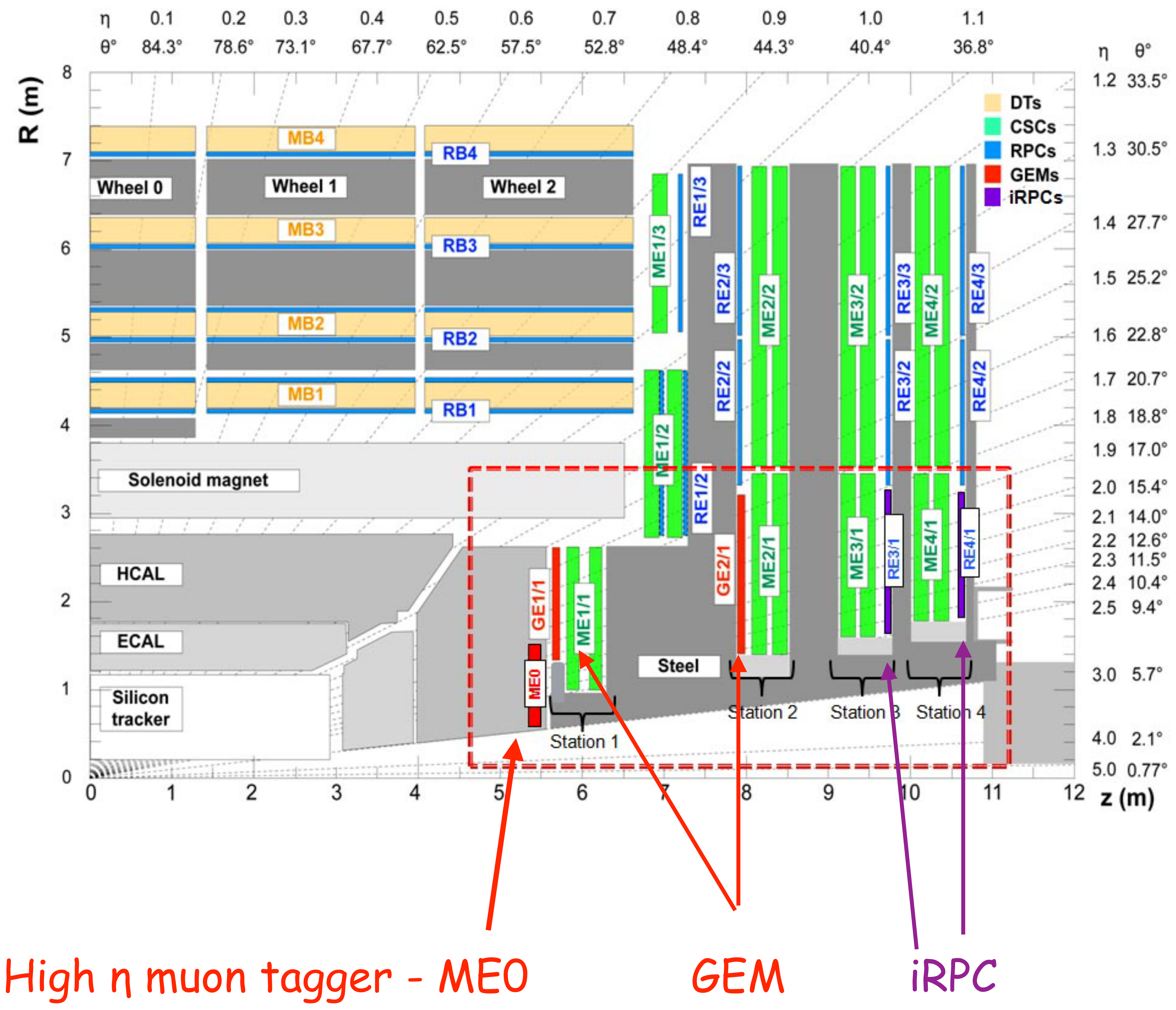
Electronics upgrade

- DT
  - New on-chamber electronics, to cope with higher rate and radiation
  - New trigger logic system to be in the service cavern - easier to maintain
- CSC
  - Selective replacement of electronics for inner ring chambers - Cathode FE board in station 1 moved to stations 2,3,4, while newer generation boards installed in station 1
- RPC
  - The “link system” (connecting the FE board to the trigger processors) to be replaced
    - For convenience of operation and maintenance
    - To fully exploits the intrinsic time resolution ~1.5 ns



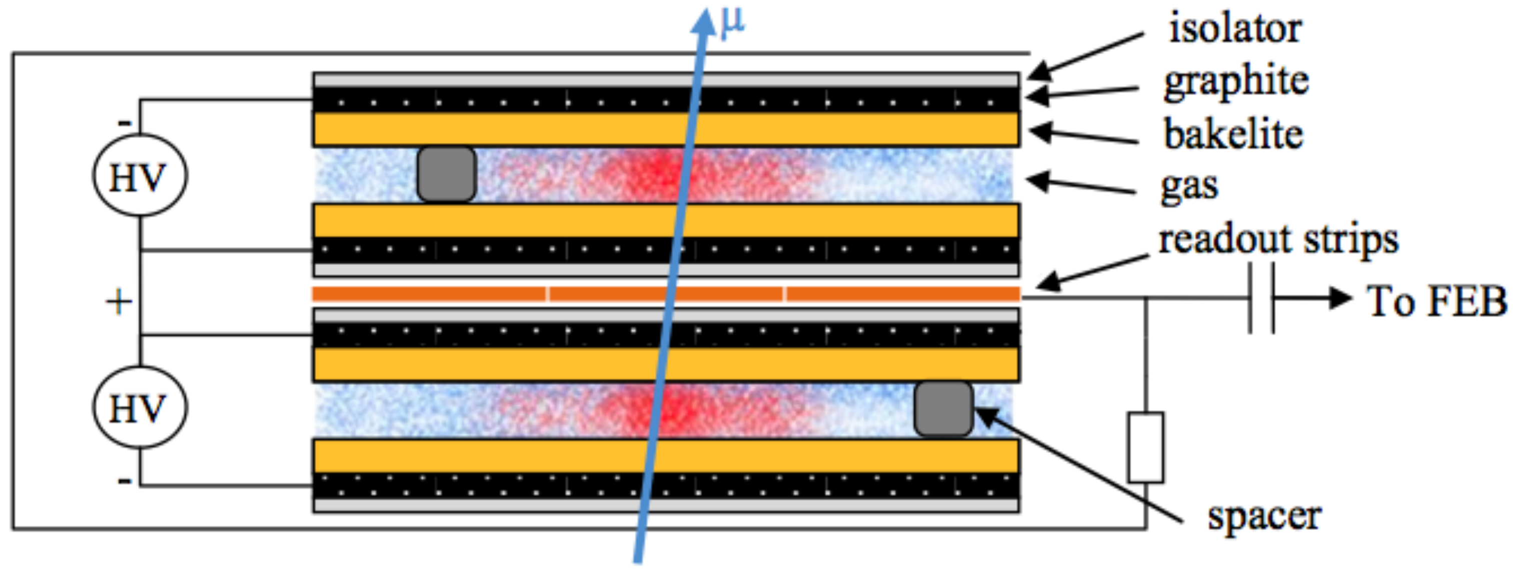


New detectors in the high η region

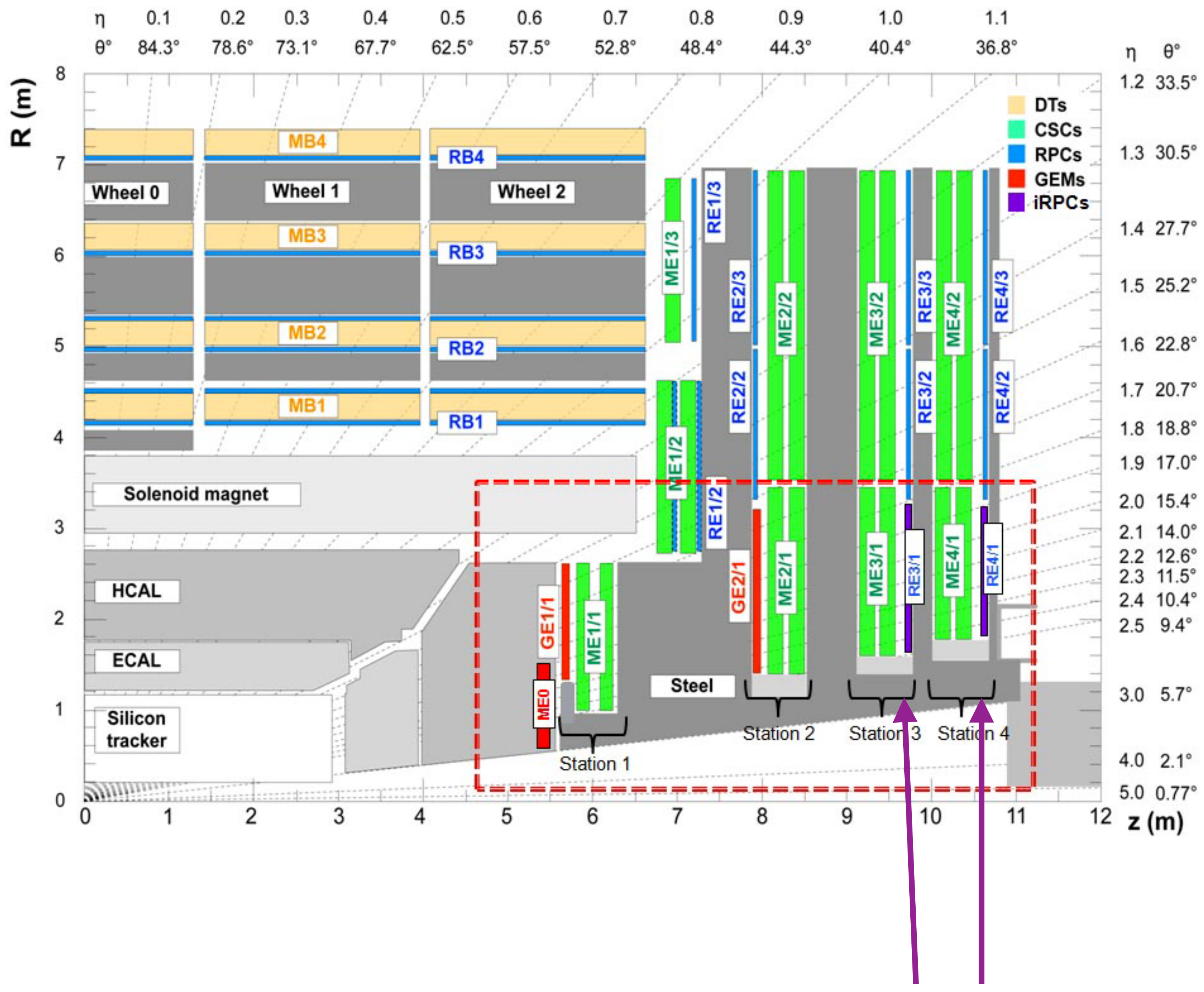


- Very challenging region
  - High rate from random hits, hadron punch-though, and muons
  - Low magnetic field => small bending of muon trajectory
- Despite harsher environment, this region has fewer hits measurement as of today
  - 1.8 < |η| < 2.4 covered only by CSC

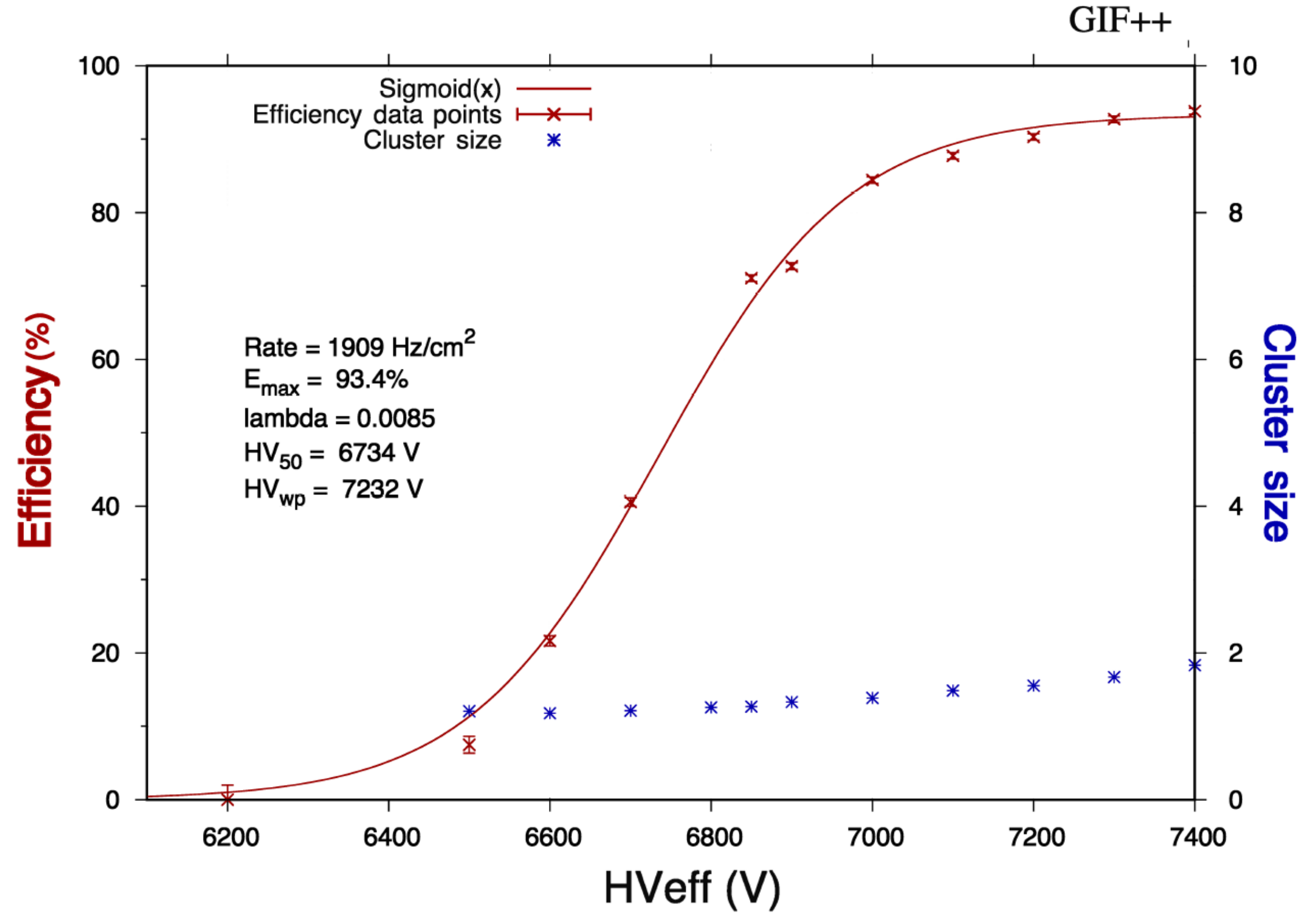
Improved RPC



- Endcap stations 3&4; 1.8 < |η| < 2.4 (RE3/1, RE4/1)
- Double-gap RPC units (same as the present RPC)
- Improved performance
  - Higher rate capability (lower resistivity, smaller gas gain)
  - Two-side strip readout
    - Providing true 2D hits with O(1) cm resolution in both dimensions

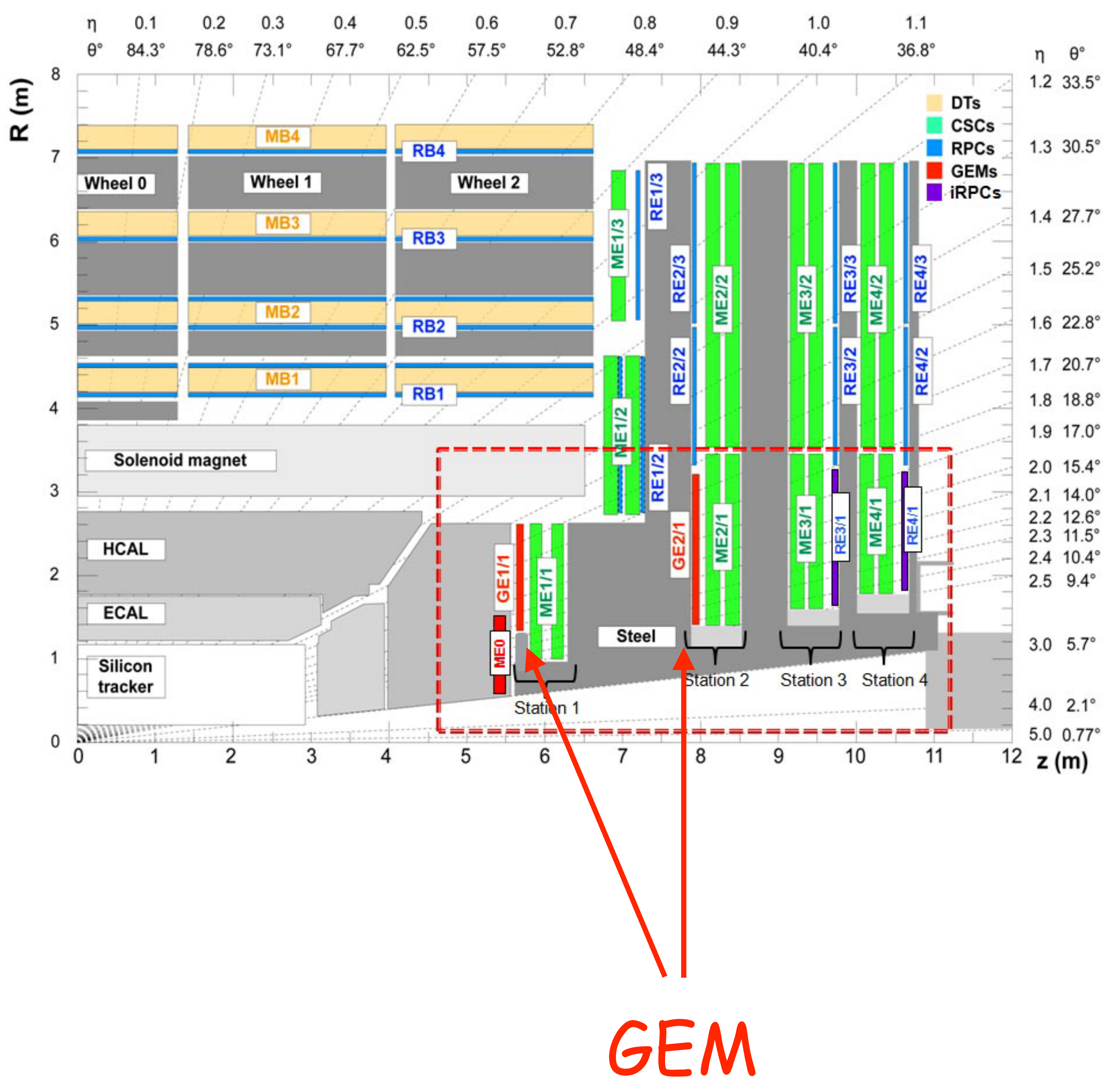


iRPC

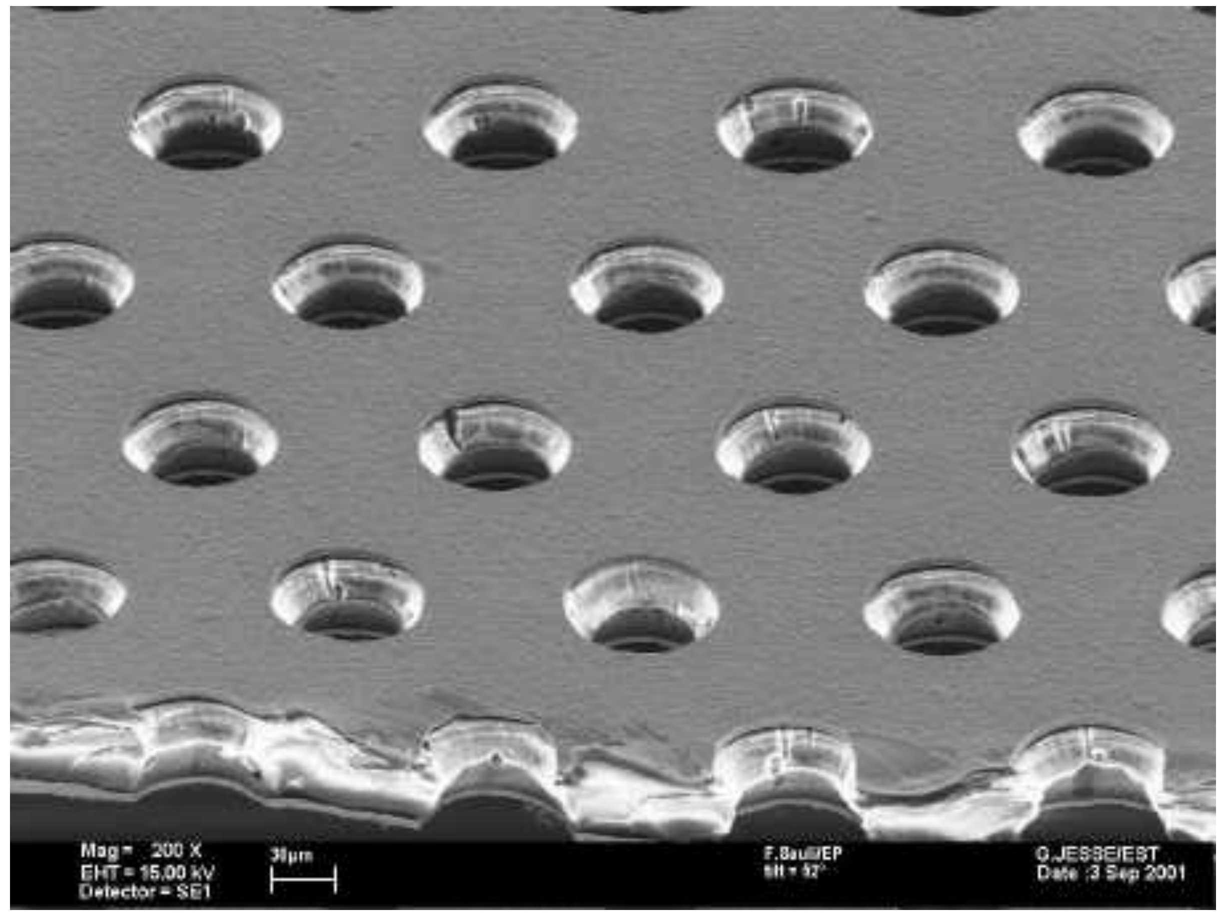


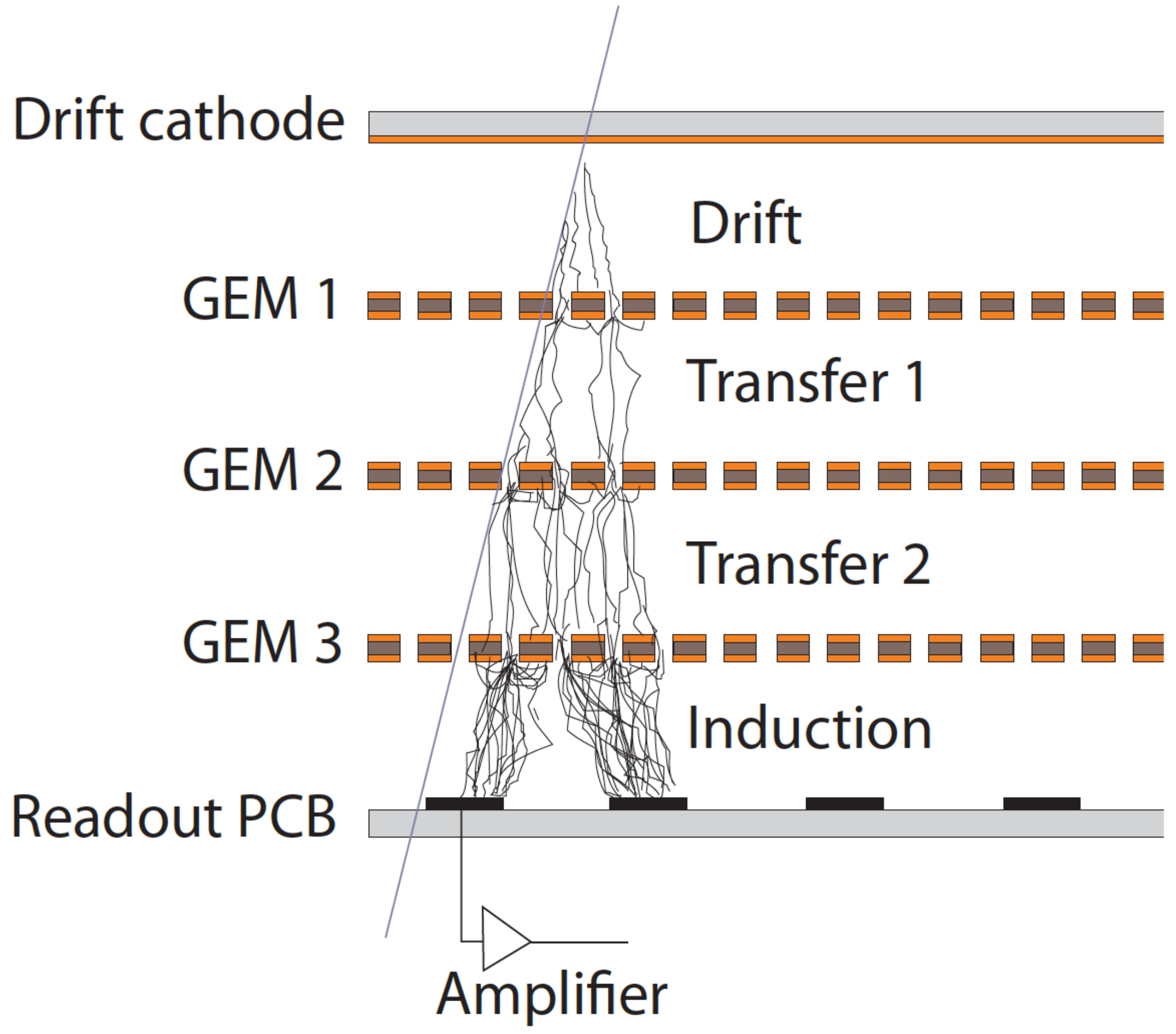
Performs well at
2 kHz/cm2
(3xHL_LHC)

GEM (Gas Electron Multiplier)

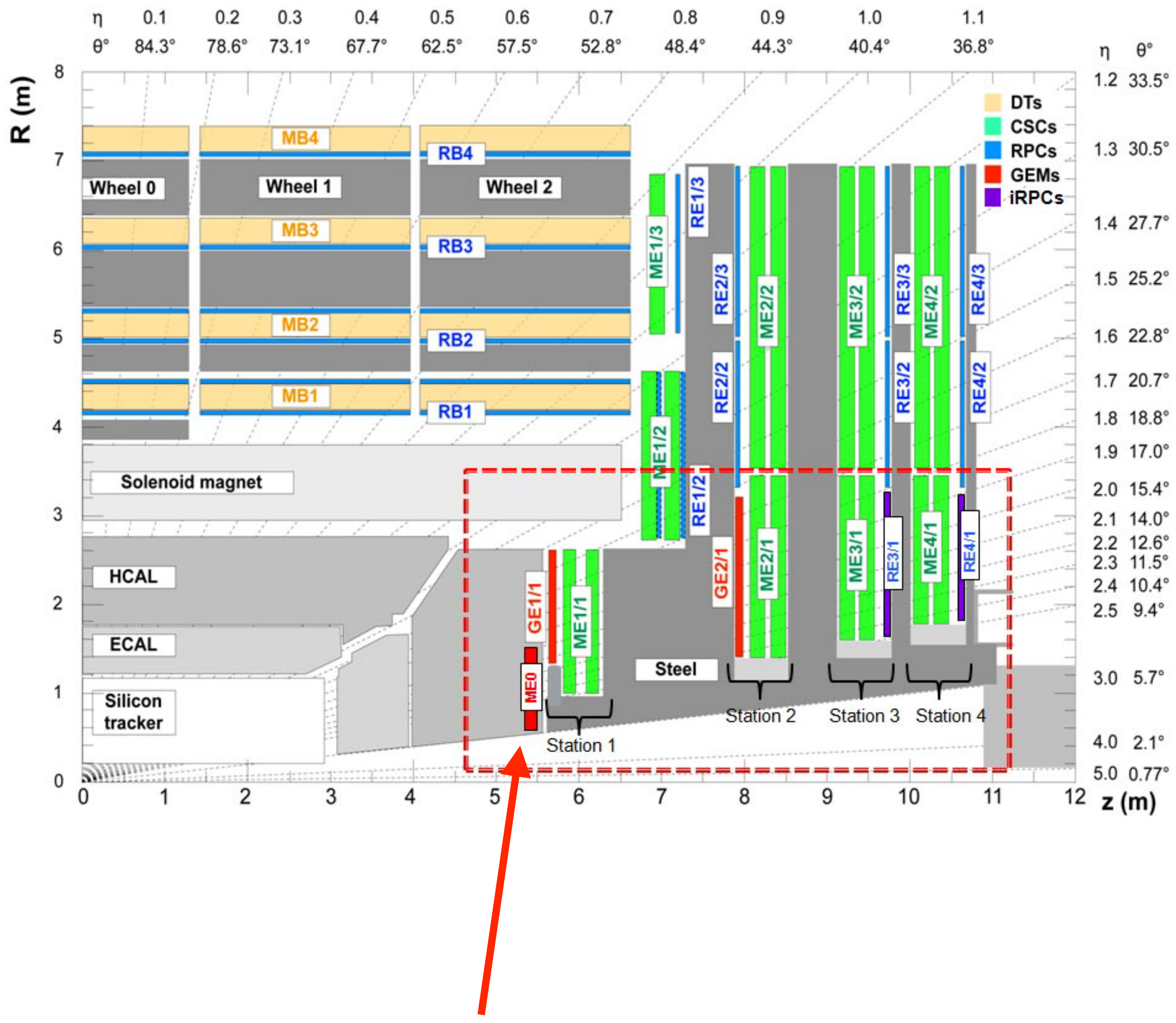


- Avalanches in strong electric filed concentrated in pin holes
- Known to operate reliably at high rate (MHz/cm2); excellent longevity
- Triplet GEM: gas gain 10^4
- Spatial resolution ~ 100 μm
- Two layers triple-GEM to be added at endcap stations 1&2
  - GE1/1: 1.6 < |η| < 2.2
  - GE2/1: 1.6 < |η| < 2.4
- A pilot system of 5 pair GEM chambers were installed in CMS at the beginning of 2017



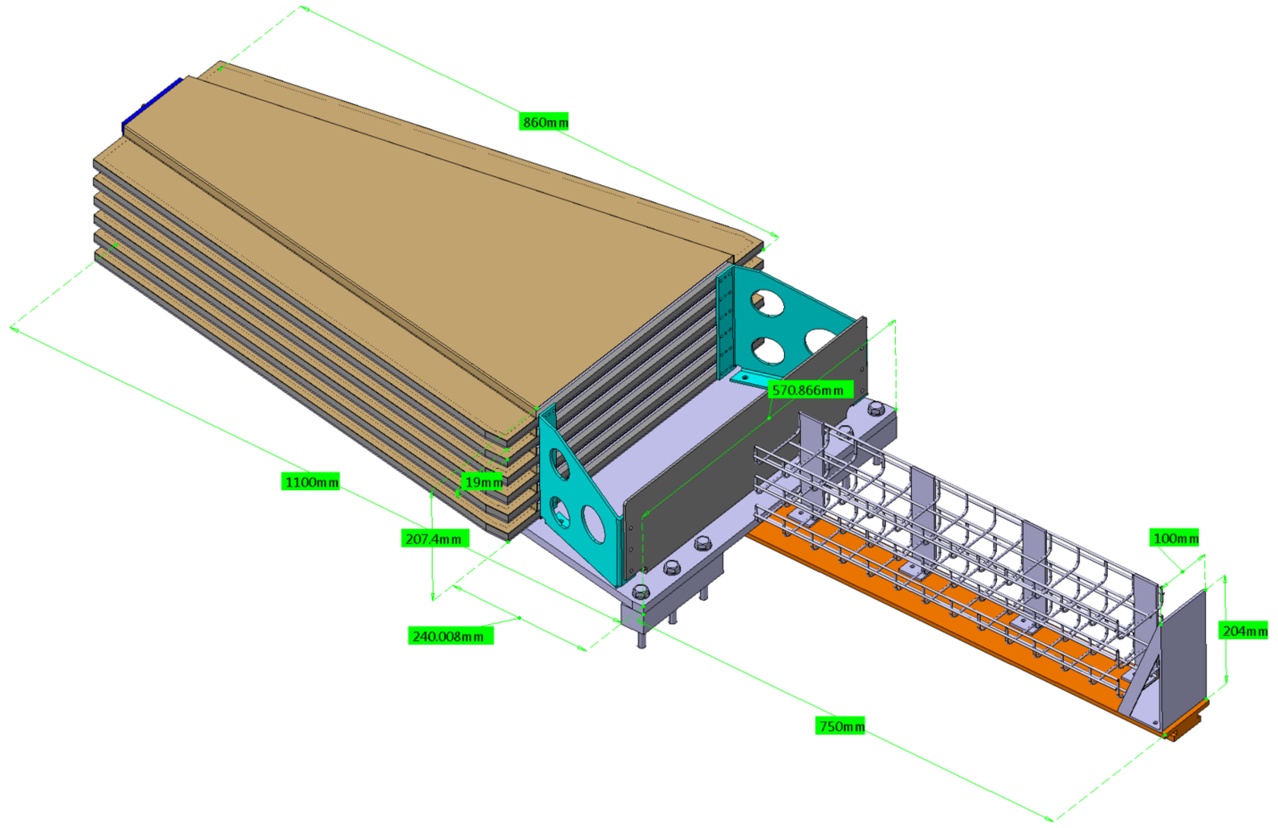


ME0 - high η muon tagger



High η muon tagger - ME0

- The same technology as GE1/1, GE2/1
- Six layers - providing "segments"
  - Muons of high p despite low pT
- Covers very high η region: 2.0 < |η| < 2.8
  - 2.0 < |η| < 2.4: CSC-ME0 tandem largely reduces trigger rate
  - 2.4 < |η| < 2.8: enlarged muon geometrical acceptance
    - Taking advantage of the extended acceptance of upgraded CMS inner pixel detector
    - Could be used not only in offline, cut also in trigger



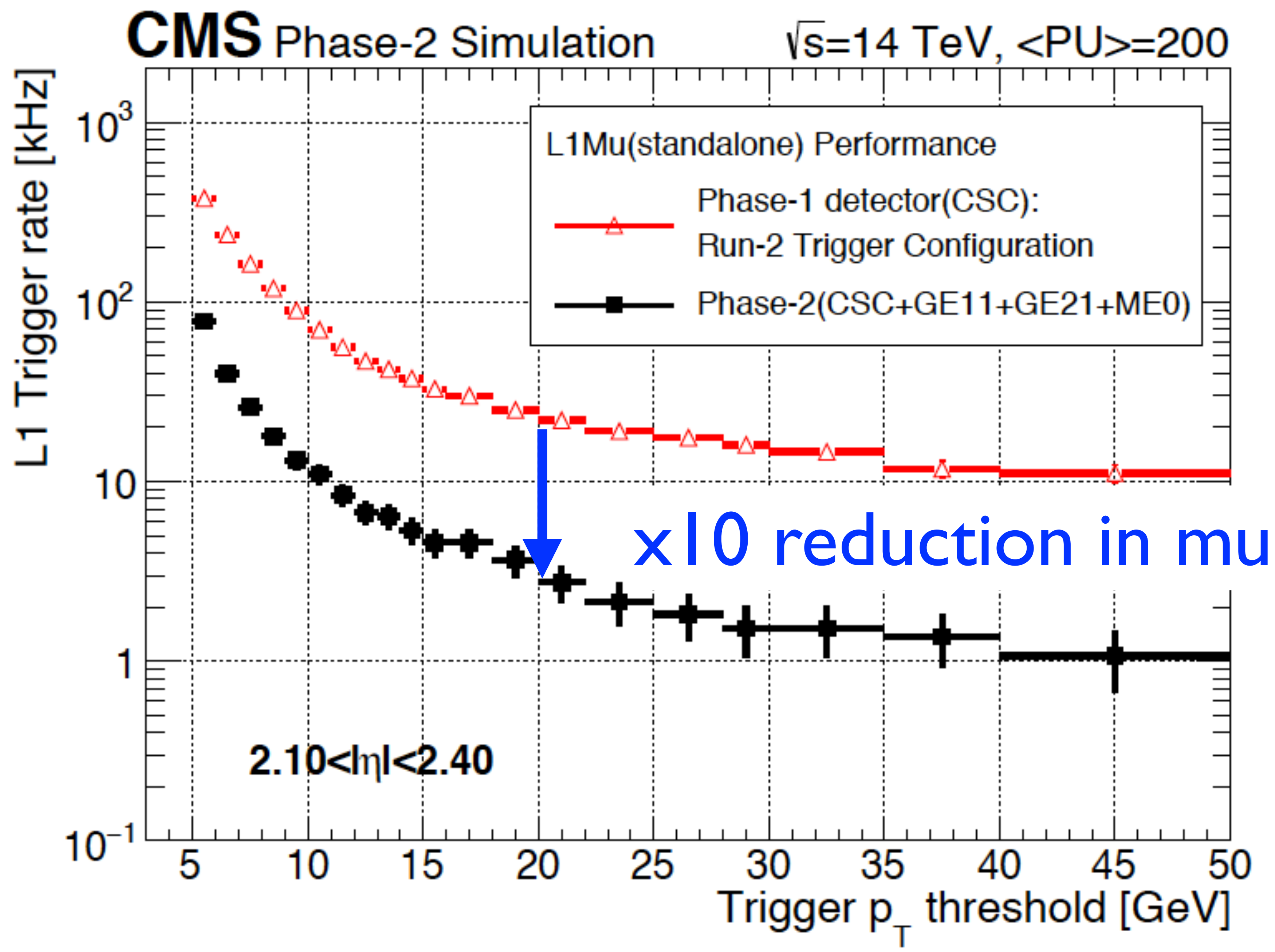
Layout of six layer stack

Muon trigger improvement

- CSC-GEM tandem (in endcap stations 1&2) improves trigger-level muon momentum measurement
- Background has steeply falling momentum spectrum

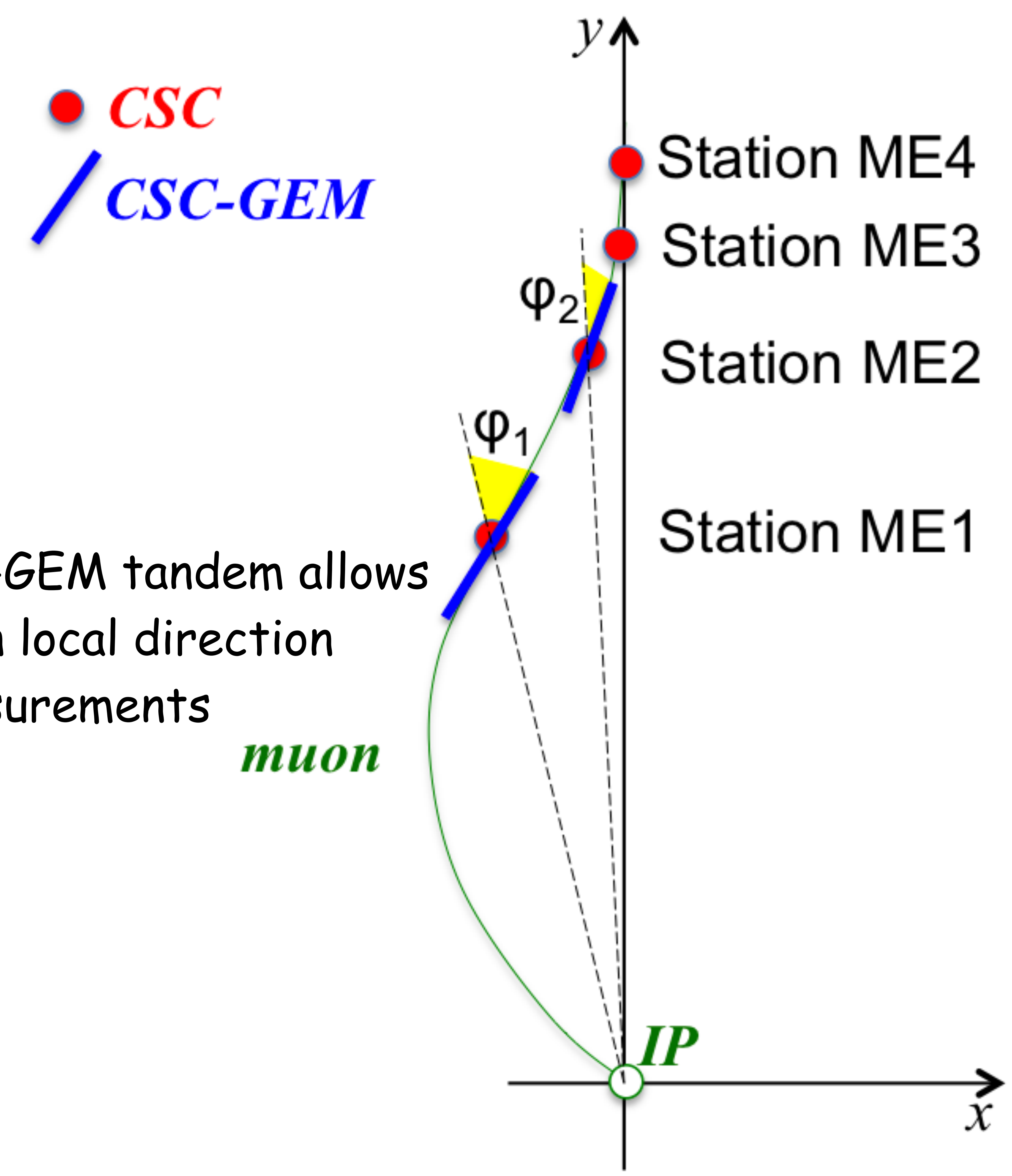
==> Trigger rate reduction

(otherwise raising trigger thresholds would harm physics acceptance)



x10 reduction in muon trigger rate

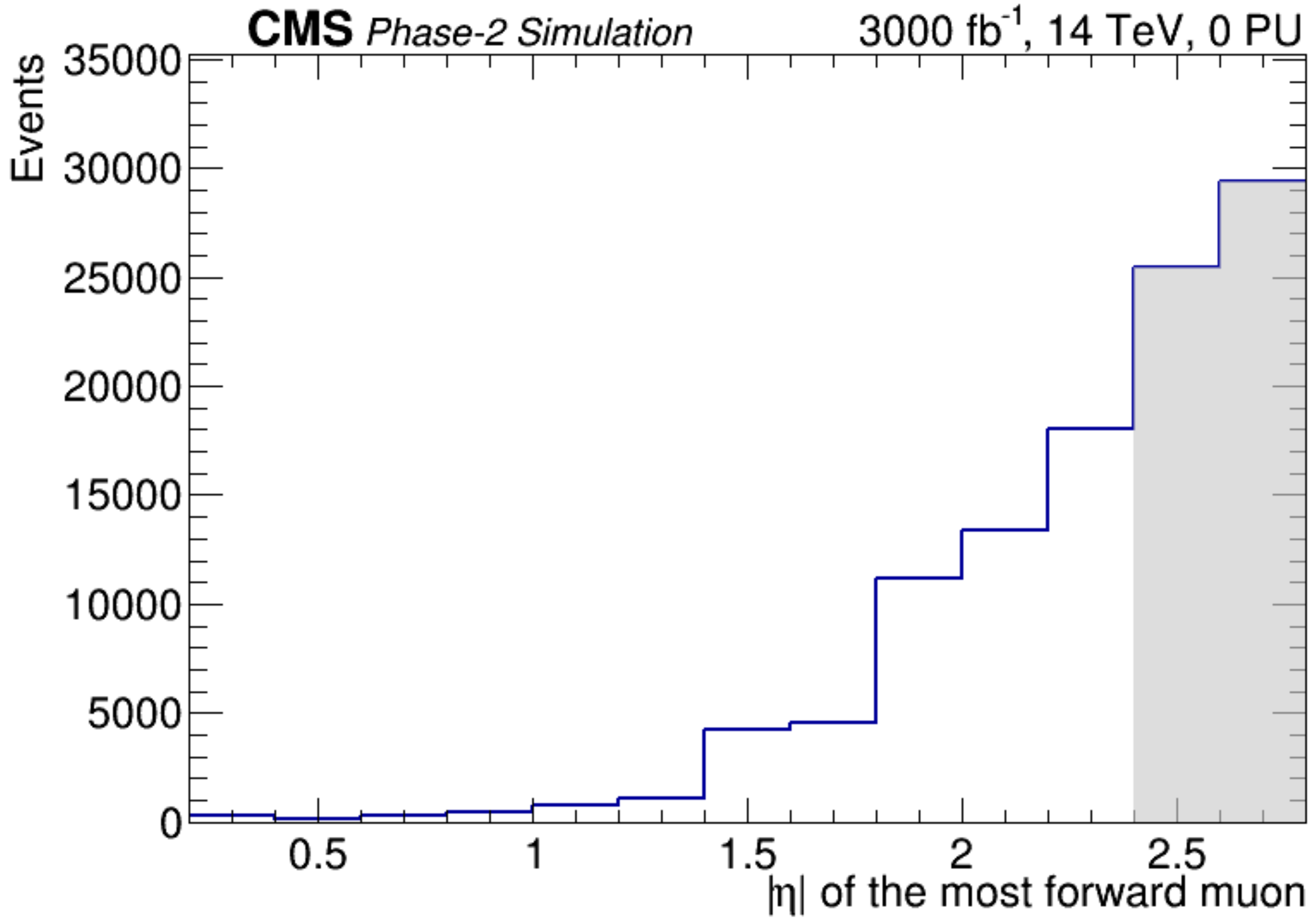
Schematic view of a muon trajectory from the collision point



CSC-GEM tandem allows muon local direction measurements

Physics performance by examples

Benefit from extended muon acceptance

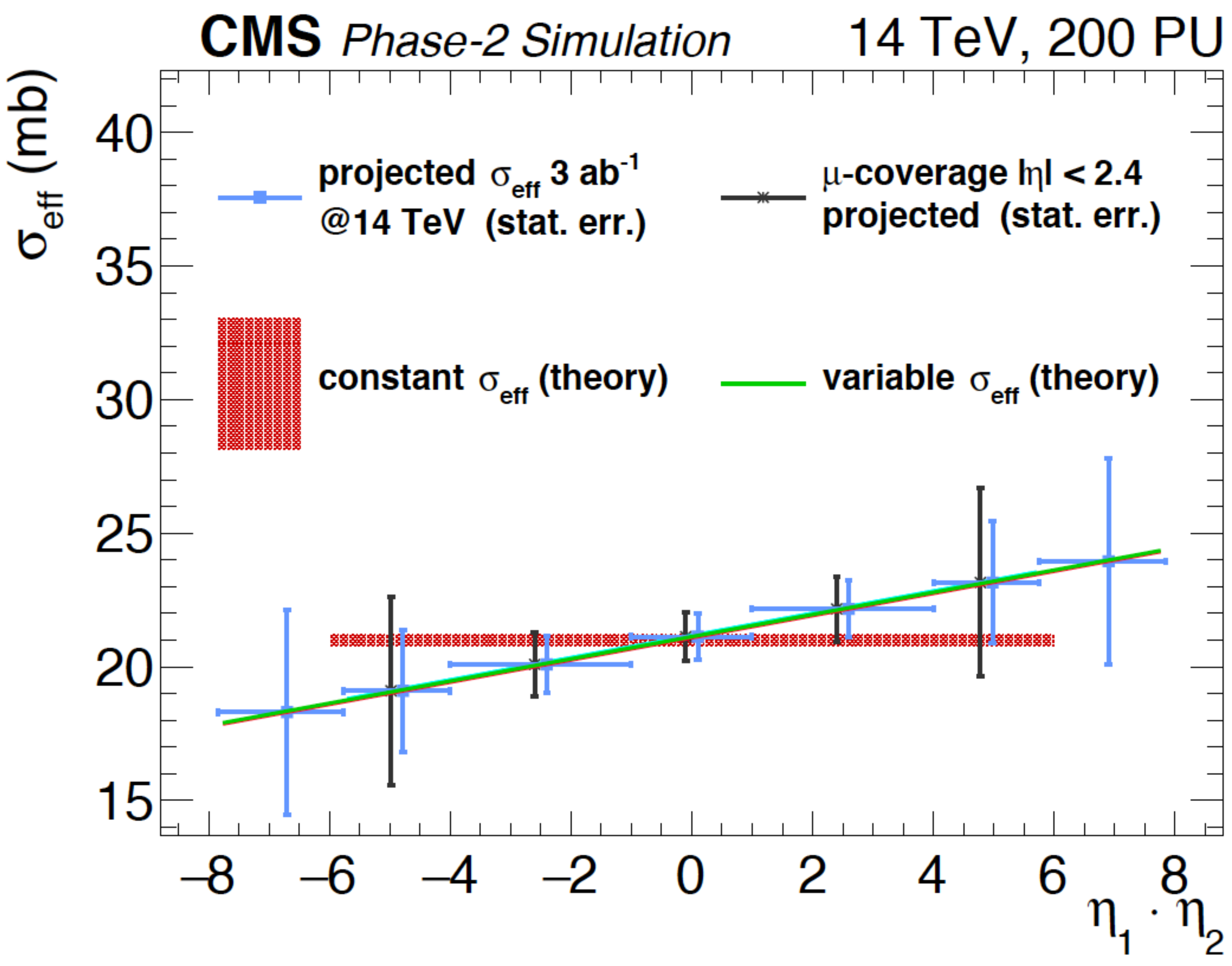


Lepton flavor violating τ->3μ search

- τ-lepton produced at LHC are of boosted to high η region (the dominant source is D/B mesons decay to tau)
- With ME0 detector, the signal acceptance is doubled at reconstruction level
- ME0 muon segments can also be used in trigger (in a multi-object trigger pattern)
- Sensitivity gain 17% by adding ME0 detector

Physics performance by examples

Benefit from extended muon acceptance



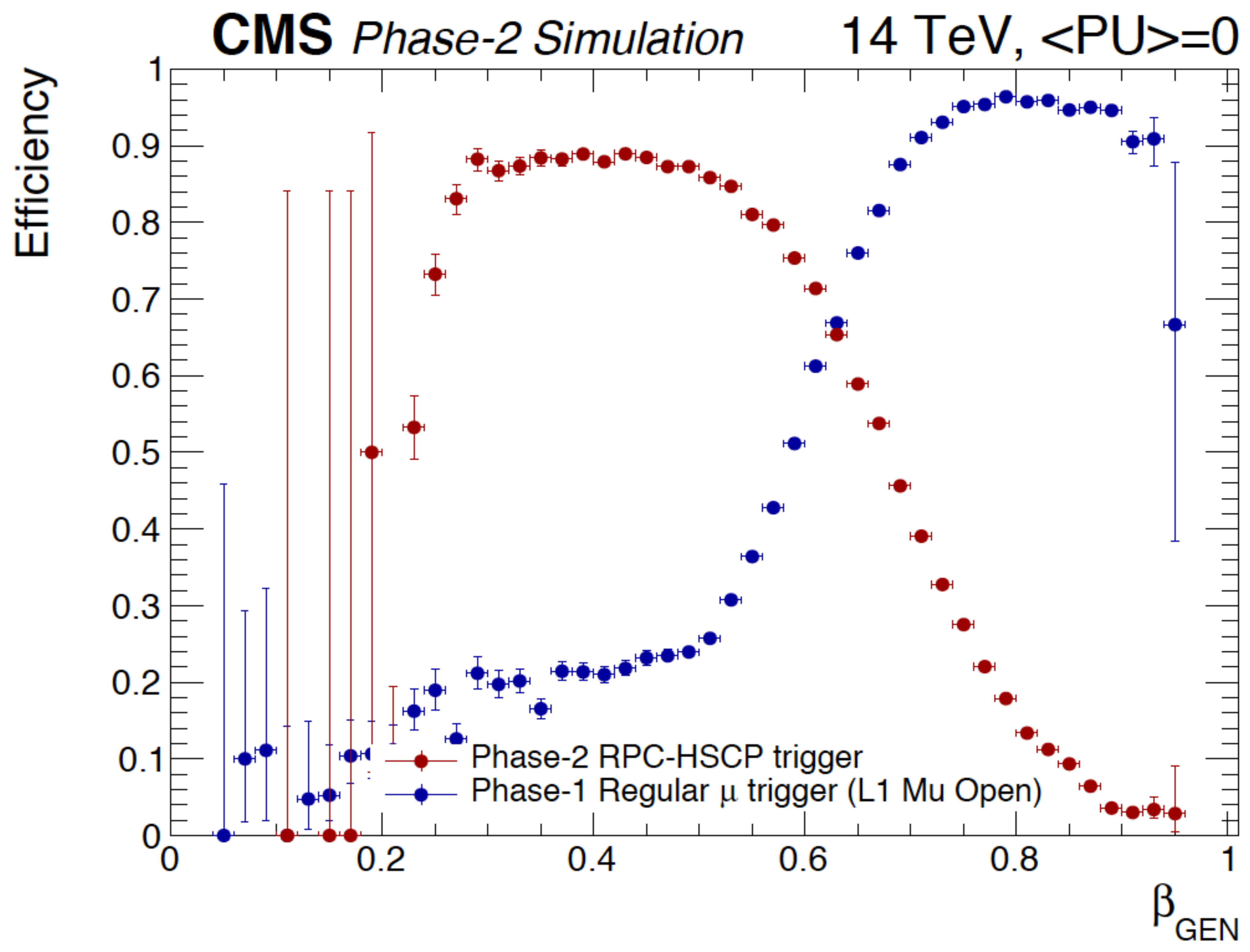
Double parton scattering pp->W+W-

- Events with both muons in the highest eta directions are the best in discriminating between different theoretical models
- Sensitivity gain 50% by adding ME0 detector

Physics performance by performance

Trigger on unconventional signals

Trigger efficiency on HSCP with RPC timing



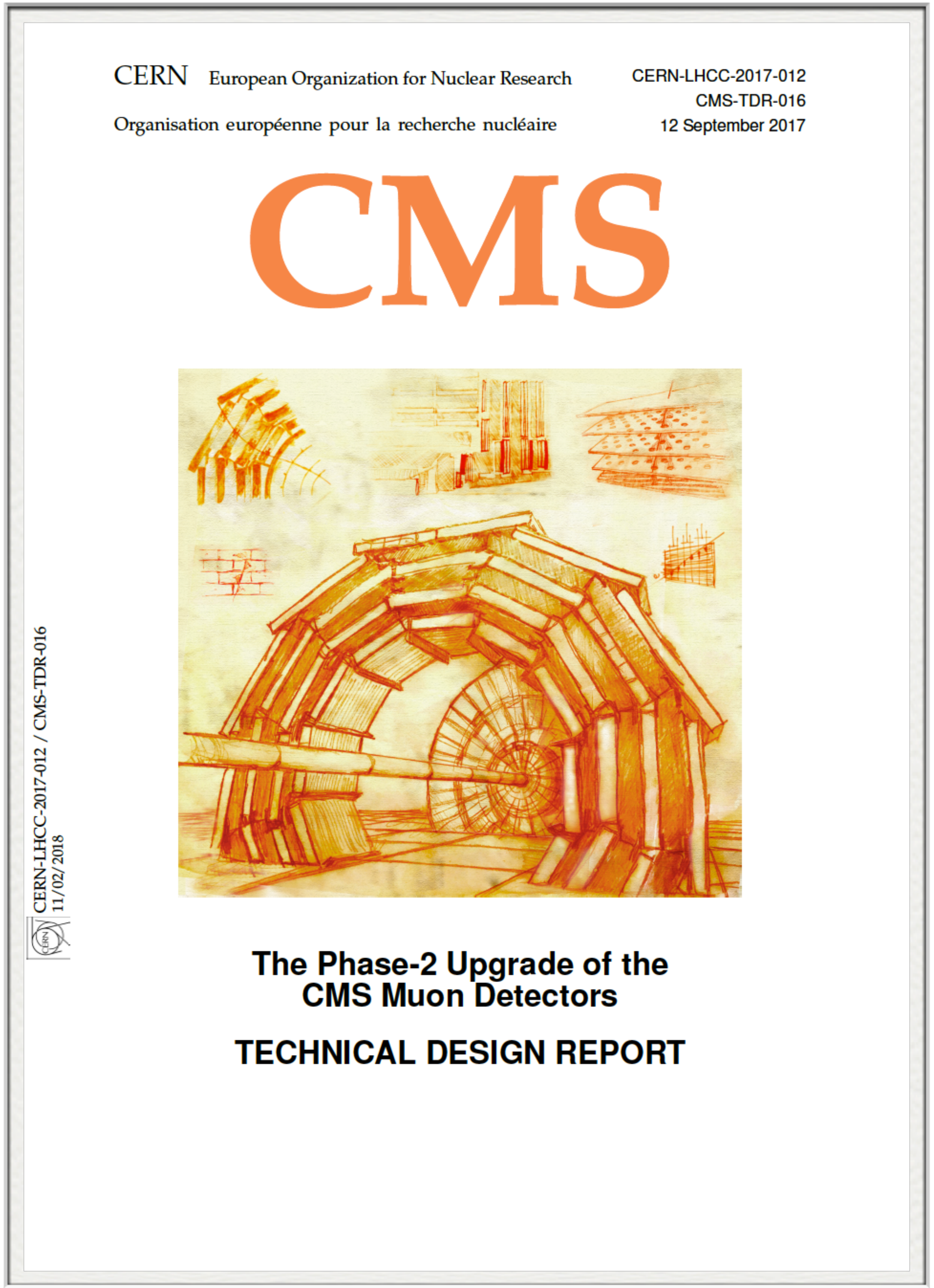
- Adding GEM makes it possible to build trigger-level muons without assuming muons come from the collision point
  - Trigger on highly displaced muons
- The upgraded RPC link system fully exploits the RPC time resolution
  - Allowing better suppression of out-of-time background
  - Enabling to identify patterns of delayed hits from one station to the next, with a precision of ~1 ns
    - Trigger on Heavy Stable Charge Particles

More information — Posters

- *Performance of the CMS Muon System in LHC Run-2, Carlo Battilana*
- *Measurement and simulation of the background in the CMS muon detectors, Cesare Calabria*
- *Upgrade program of the RPC system of the CMS Muon Spectrometer, Andrea Gelmi*
- *Commissioning and performance of the GE1/1 slice test detectors, Ilaria Vai*
- *Aging Phenomena and Discharge Probability Studies of the triple-GEM detectors for future upgrades of the CMS muon high rate region at the HL-LHC, Francesco Fallavollita*
- *Impact of Single-Mask Hole Asymmetry on the properties of GEM Detectors, Aashaq Shah*
- *Production and quality control of the new chambers with GEM technology in the CMS muon system, Rosamaria Venditti*

Summary

- CMS Muon system upgrade
    - Present DT, CSC, RPC detectors will stay
    - Electronics to be selectively replaced to meet HL-LHC requirements
    - The high η region to be enhanced with additional iRPC, GEM and ME0 detectors
    - Upgraded detector capabilities open windows for new physics opportunities
- CMS Muon Upgrade TDR is published
- Installation starts in the Long Shutdown 2 (2019-2020); continues in Year-End-Techinical-Stops; and finishes in the Long Shutdown 3 (2024-mid 2026)



CERN European Organization for Nuclear Research
Organisation européenne pour la recherche nucléaire

CERN-LHCC-2017-012
CMS-TDR-016
12 September 2017

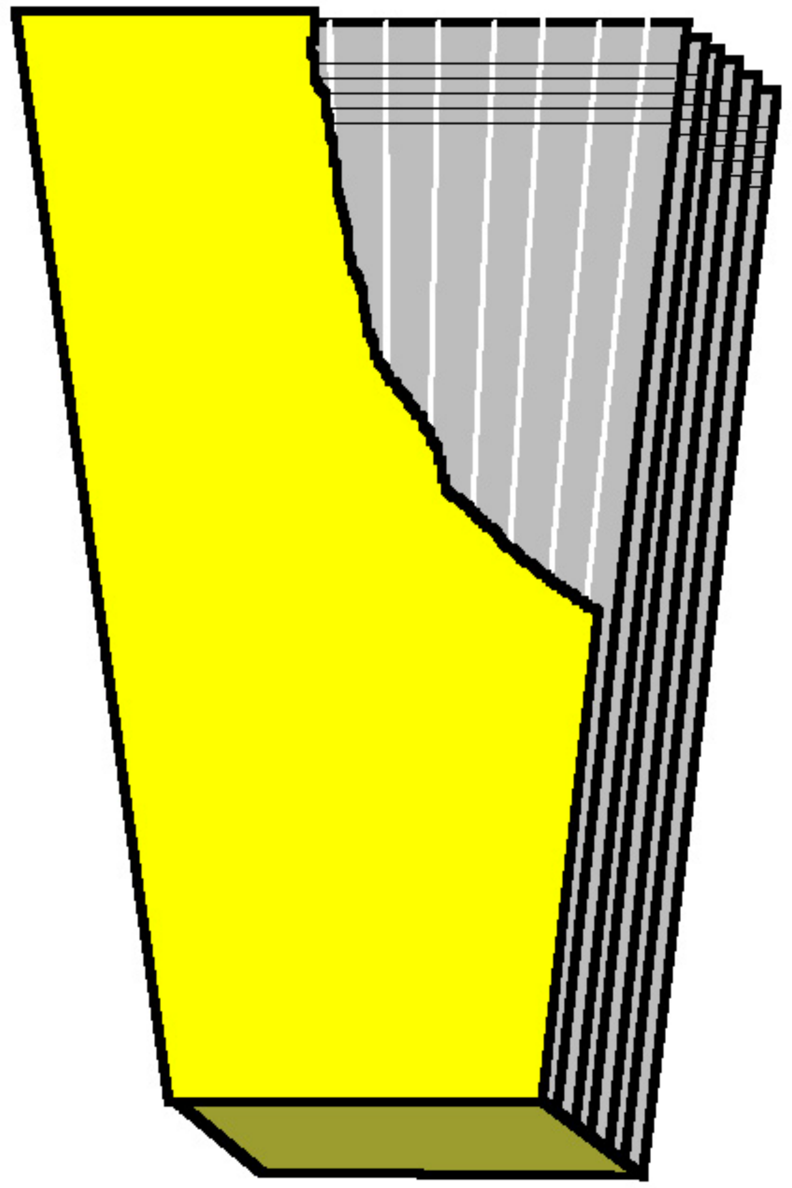
CMS

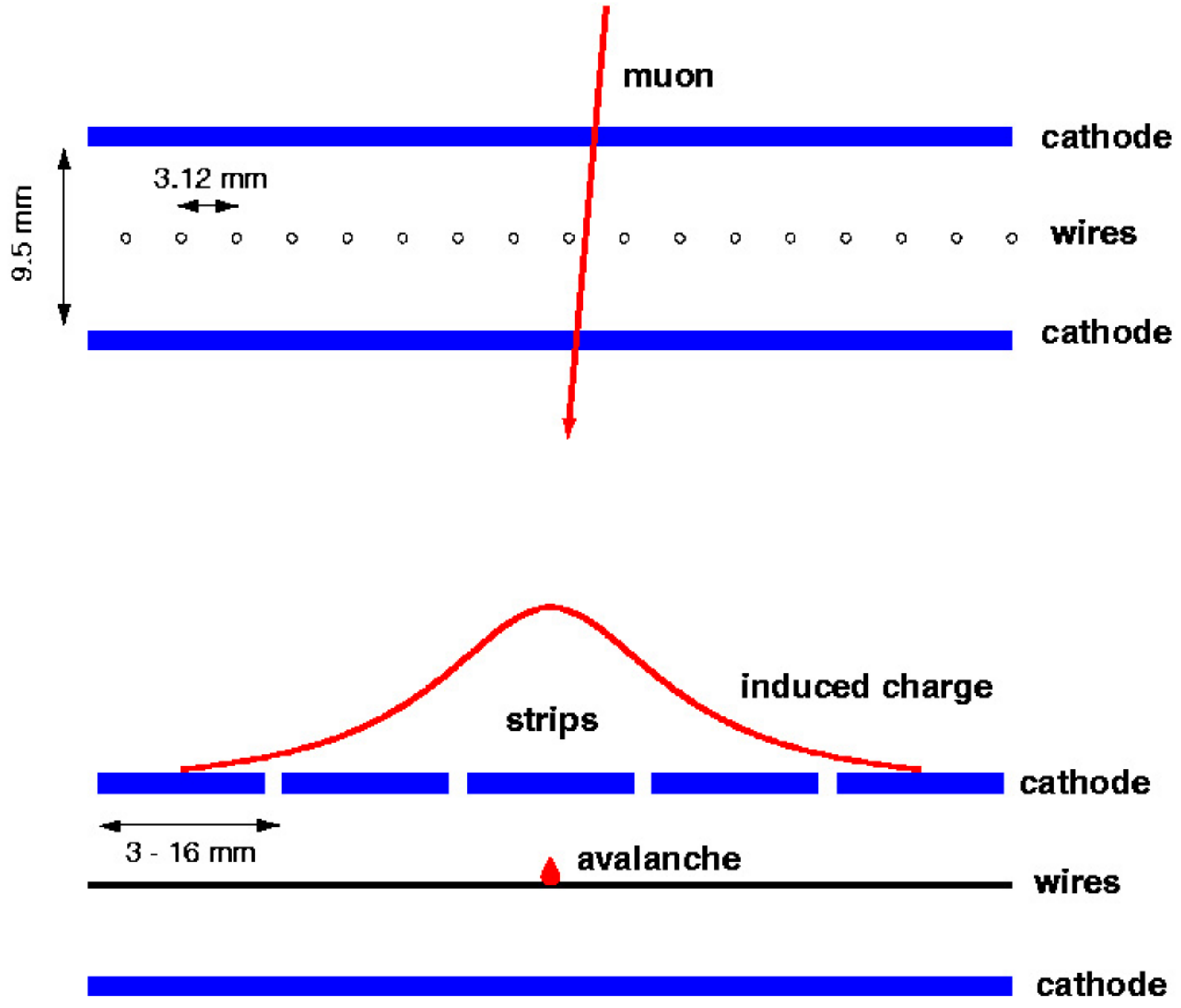
CERN-LHCC-2017-012 / CMS-TDR-016
11/02/2018

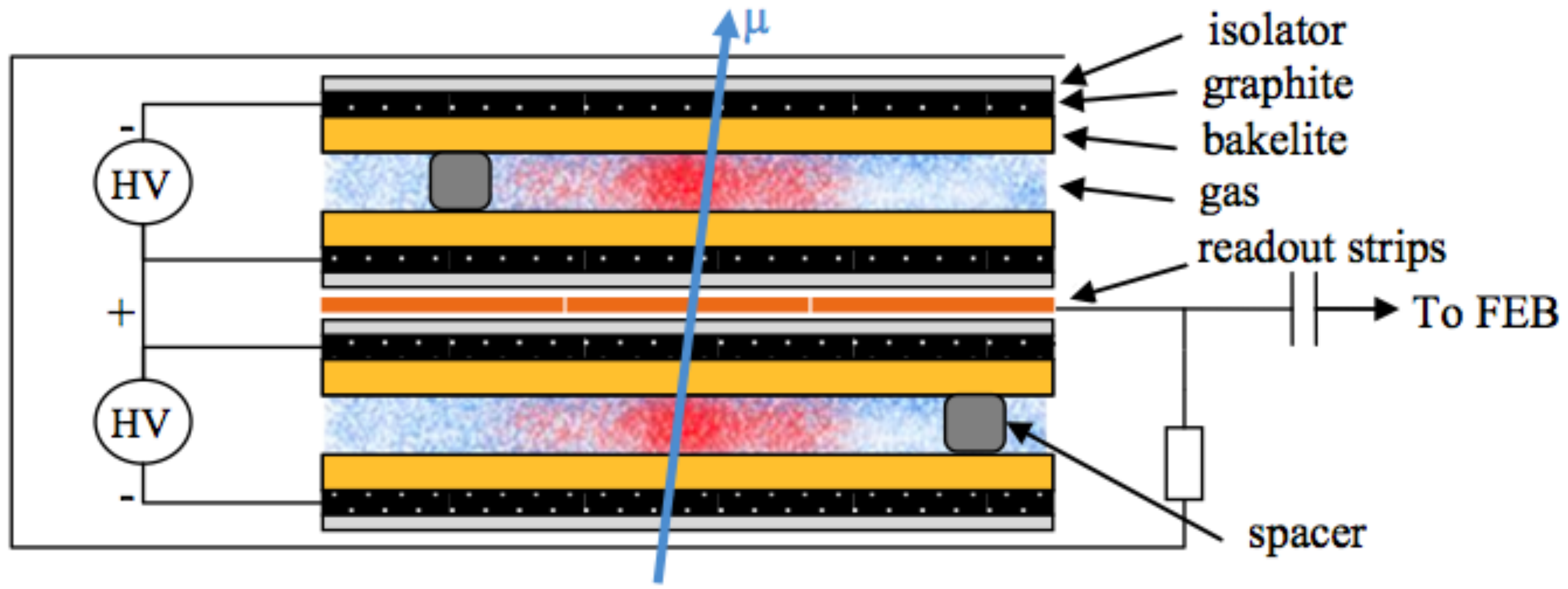
The Phase-2 Upgrade of the CMS Muon Detectors

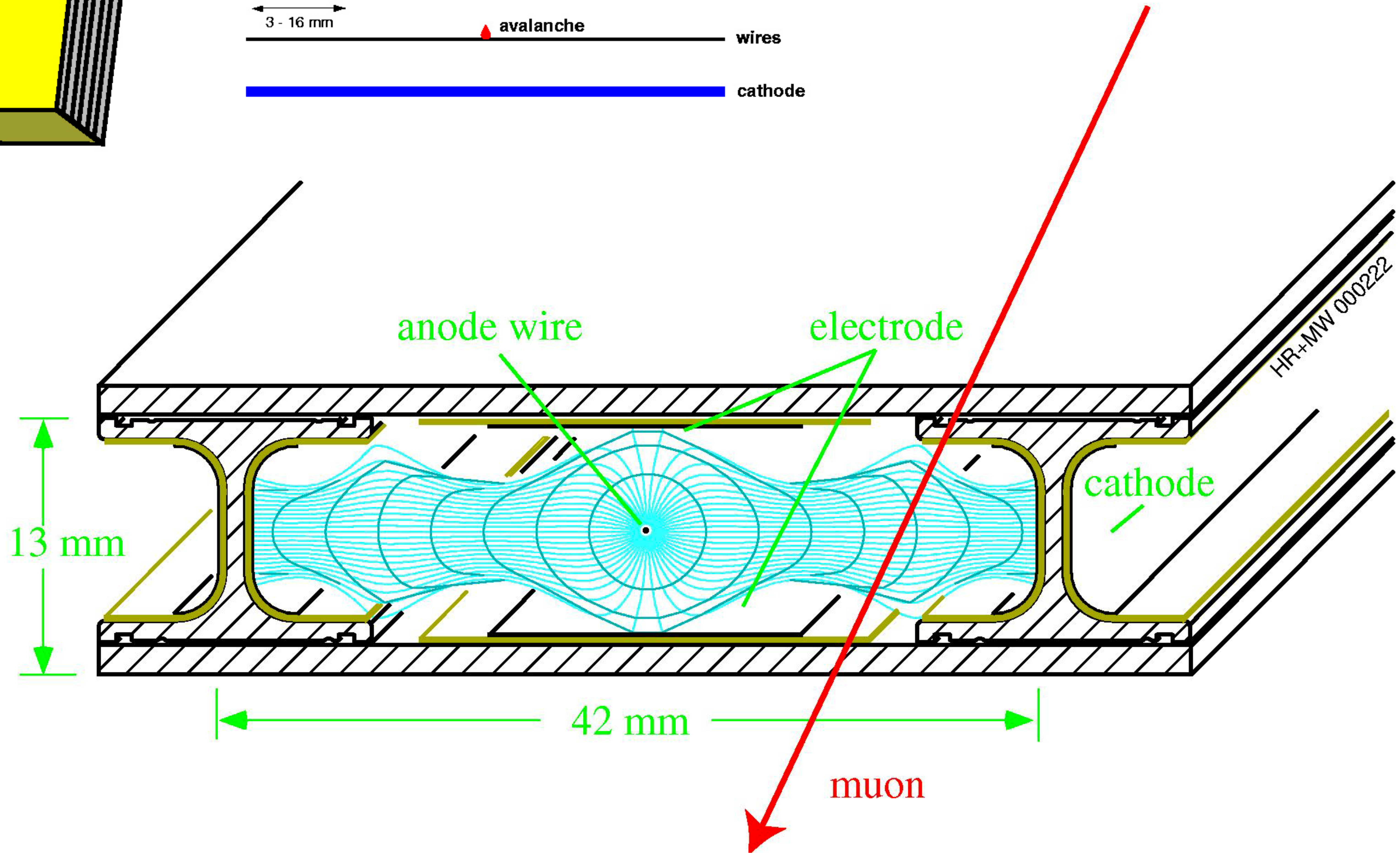
TECHNICAL DESIGN REPORT

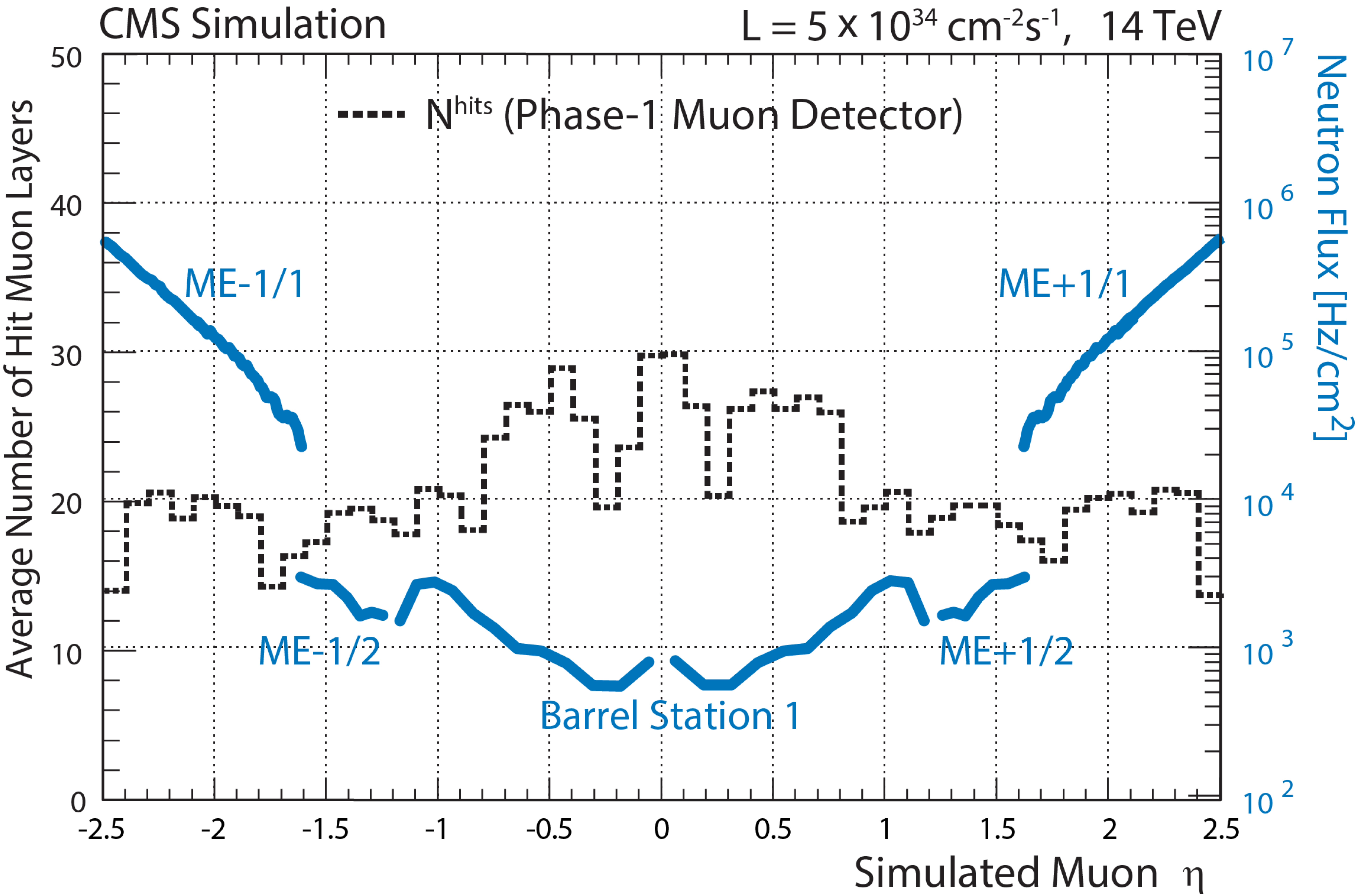
Back-up




muon
cathode
3.12 mm
9.5 mm
wires
cathode
induced charge
strips
cathode
3 - 16 mm
avalanche
wires
cathode


μ
isolator
graphite
bakelite
gas
readout strips
To FEB
HV
HV
+
spacer


anode wire
electrode
HR+MW 000222
cathode
13 mm
42 mm
muon



CMS Simulation
L = 5 x 10^34 cm^-2s^-1, 14 TeV
N^hits (Phase-1 Muon Detector)
ME-1/1
ME+1/1
ME-1/2
ME+1/2
Barrel Station 1
Average Number of Hit Muon Layers
Neutron Flux [Hz/cm^2]
Simulated Muon η
50
40
30
20
10
0
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
10^7
10^6
10^5
10^4
10^3
10^2

	HL-LHC needs	CMS 2017	CMS upgraded
Level-1 trigger accept rate (kHz)	500	DT: < 300 CSC: < 250	DT: $\gg 500$ CSC: 4000
Level-1 latency (μs)	12.5	DT: 20 CSC: 3.6	DT: $\gg 12.5$ CSC: 28.8
Total DAQ data transfer rate (Gbit/s)	DT: 1082 CSC: 1026	DT: 42 CSC: 230	DT: 3600 CSC: 2764

Eco-friendlier gas

- New regulations
  - In 2014, the European Commission adopted a new regulation limiting the total amount of important fluorinated greenhouse gases (F-gases) that can be sold in the EU from 2015 onward and phasing them down in steps to one-fifth of 2014 sales in 2030
- CSC and RPC F-gas footprint
  - 1700 m3/hr of CO_2 equivalent (yearly, 12K cars)
  - F-gases used by CSC and RPC prevent ageing and ensure reliable operation
- Solutions
  - new eco-friendlier gas options -> RPC explore operation with CF_3I, $C_3H_2F_4$ (GWP 0,4)
  - F-gas consumption reduction -> CSC explore operation with 2% CF_4
  - Other measures being explored