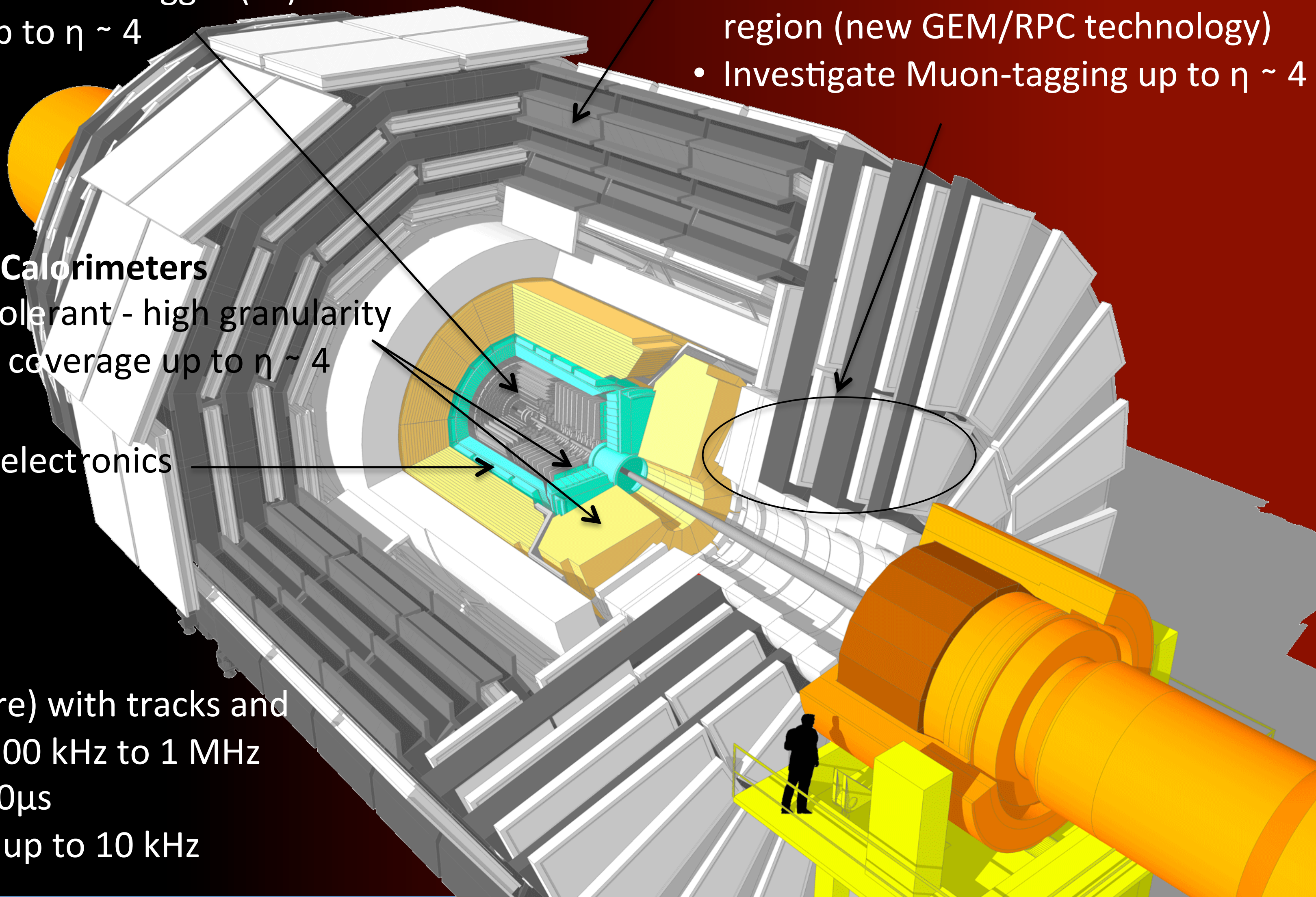
# CMS Phase 2 Upgrades

**New Tracker**
- Radiation tolerant - high granularity - less material
- Tracks in hardware trigger (L1)
- Coverage up to η ~ 4

**Muons**
- Replace DT FE electronics
- Complete RPC coverage in forward region (new GEM/RPC technology)
- Investigate Muon-tagging up to η ~ 4



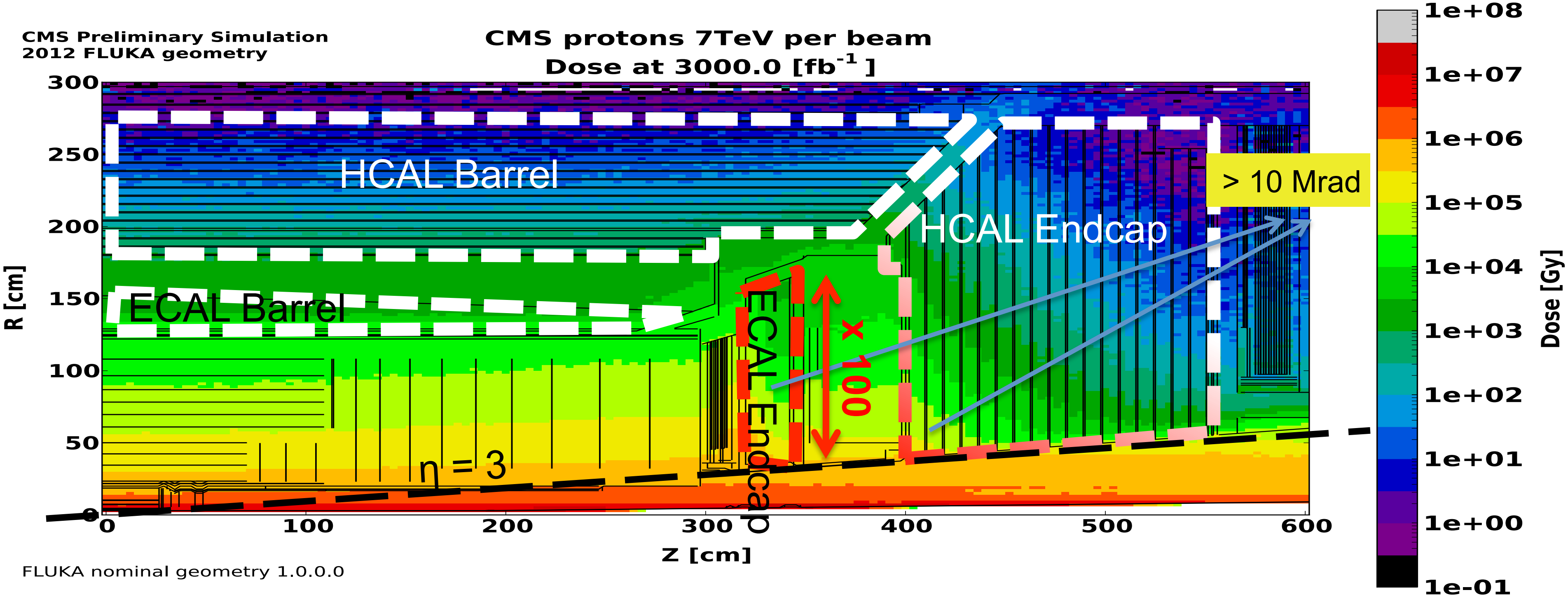
**New Endcap Calorimeters**
- Radiation tolerant - high granularity
- Investigate coverage up to η ~ 4

**Barrel ECAL**
- Replace FE electronics

**Trigger/DAQ**
- L1 (hardware) with tracks and rate up ~ 500 kHz to 1 MHz
- Latency ≥ 10μs
- HLT output up to 10 kHz

# Radiation and piluep environment

- Radiation six times higher than nominal LHC design
- 5(7)E34 Hz/cm$^2$ ➔ ~ 140 (200) collisions/bunch crossing




**Longevity studies and simulation for 300 fb$^{-1}$/y ➔ 3000 fb$^{-1}$ total**

# LHC long term schedule (Dec 2013)

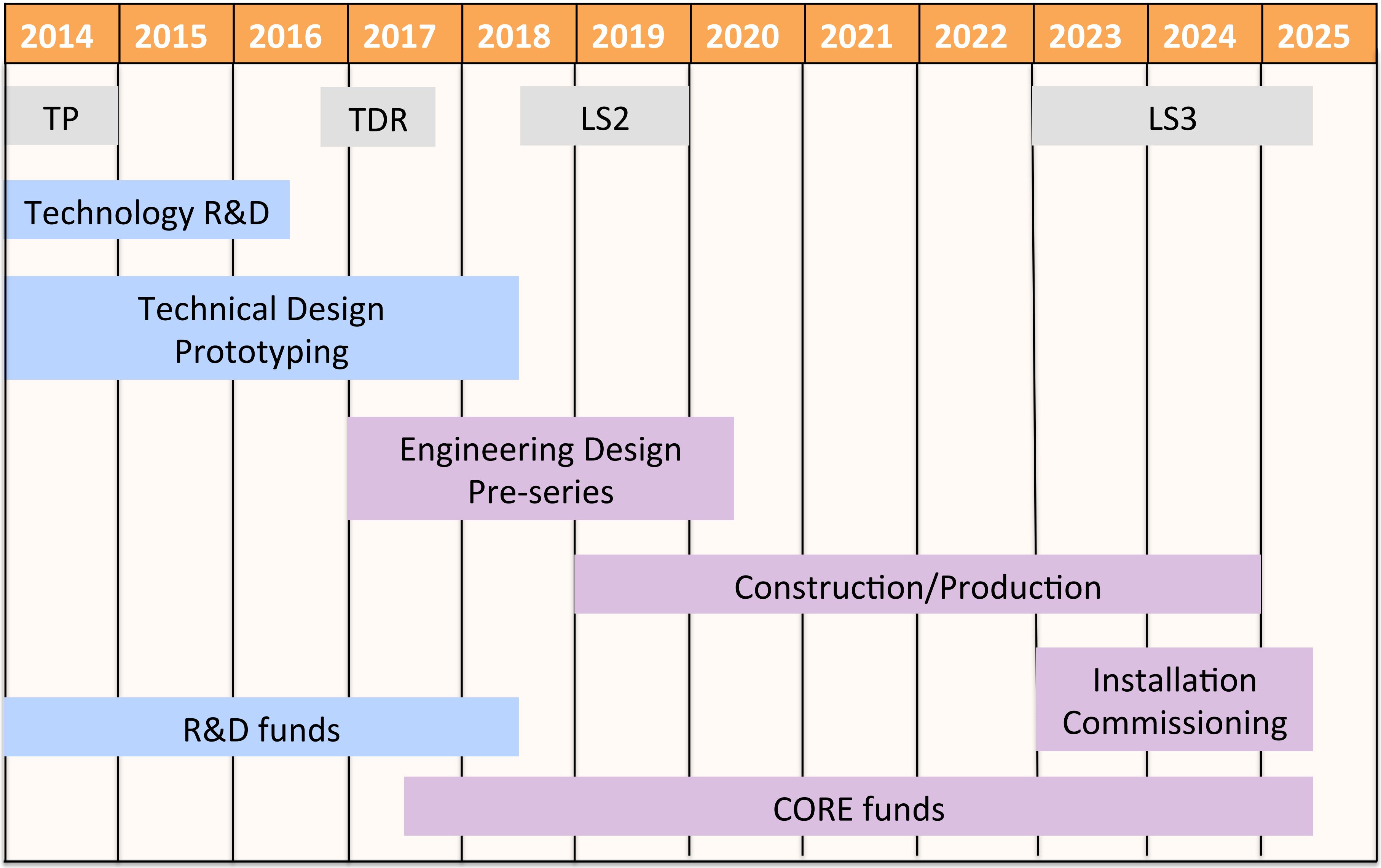
**CMS Technical Proposal end 2014**
**CMS Technical Design Reports 2016-17**

## LHC schedule beyond LS1

Only EYETS (19 weeks) (no Linac4 connection during Run2)
LS2 starting in 2018 (July) 18 months + 3months BC (Beam Commissioning)
LS3 LHC: starting in 2023 => 30 months + 3 BC
injectors: in 2024 => 13 months + 3 BC

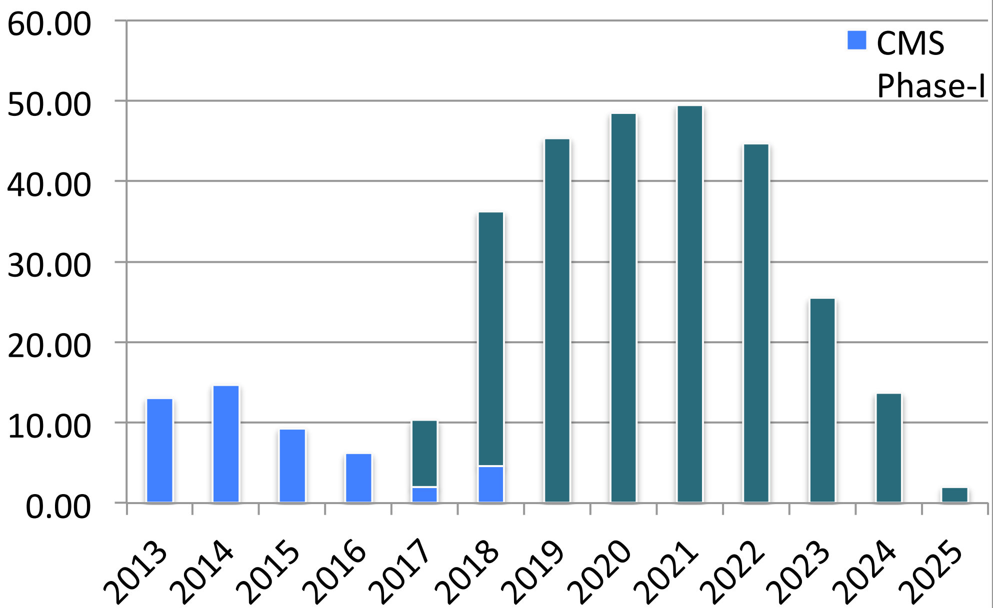
# CMS steps for Phase 2 completion

based on Dec. 13 schedule



# Phase 2 Upgrades Resource Profile

Phase 2 total estimate ~269 M CHF (October 2013):
initial estimate to be reviewed for TP (2014) and TDRs (2016-17)

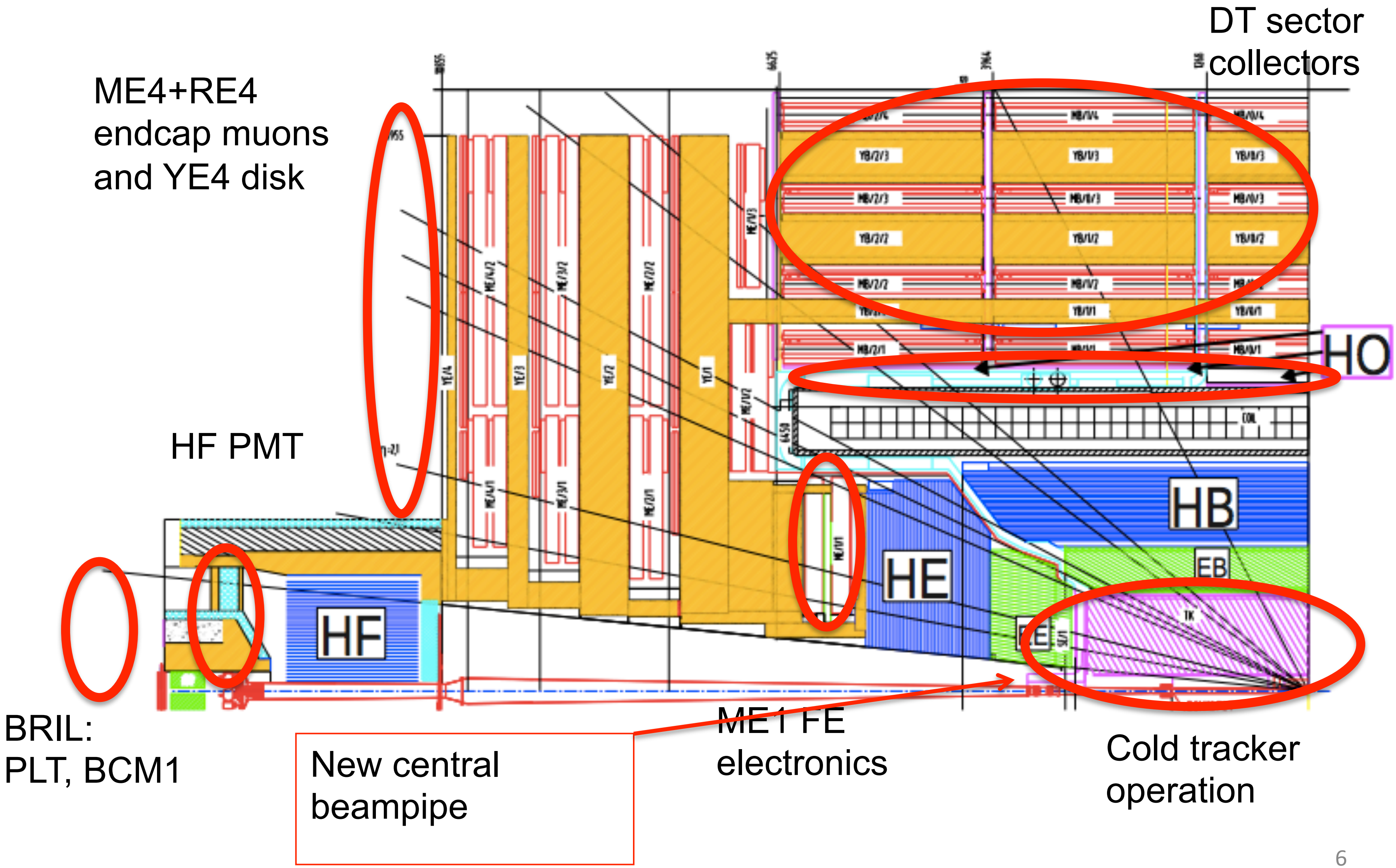



| Summary of Phase 2 Costs | | |
|---|---|---|
| **Item** | **Sub-item** | **Estimated CORE Cost (MCHF 2013)** |
| | Silicon Tracker | 94 |
| | Pixel Detector | 34 |
| **Tracker** | | **127** |
| | Endcap Calorimeter Upgrade: EM & HAD | 67 |
| | HF upgrade to 4-channels per PMT | 2 |
| **Calorimeters** | | **69** |
| | DT Electronics | 7 |
| | Endcap Muon System Upgrade | 12 |
| | High Eta Muon Tagging Station | 6 |
| **Muon System** | | **25** |
| | L1-Trigger | 7 |
| | EB Frontend Electronics | 11 |
| **Trigger System and Front-end Electronics** | | **18** |
| | DAQ system: Clock, Readout, Network | 5 |
| | HLT | 6 |
| **DAQ and HLT** | | **11** |
| | Shielding Changes for HL-LHC | 6 |
| | Tooling, rail systems, cranes for LS3 work | 5 |
| | Common Systems and Installation | 9 |
| **Infrastructure and Common Systems** | | **19** |
| **Total** | | **269** |

Table 3.1.1: Summary of CORE costs for the CMS Phase 2 Upgrade

**https://cds.cern.ch/record/1605208/files/CERN-RRB-2013-124.pdf**

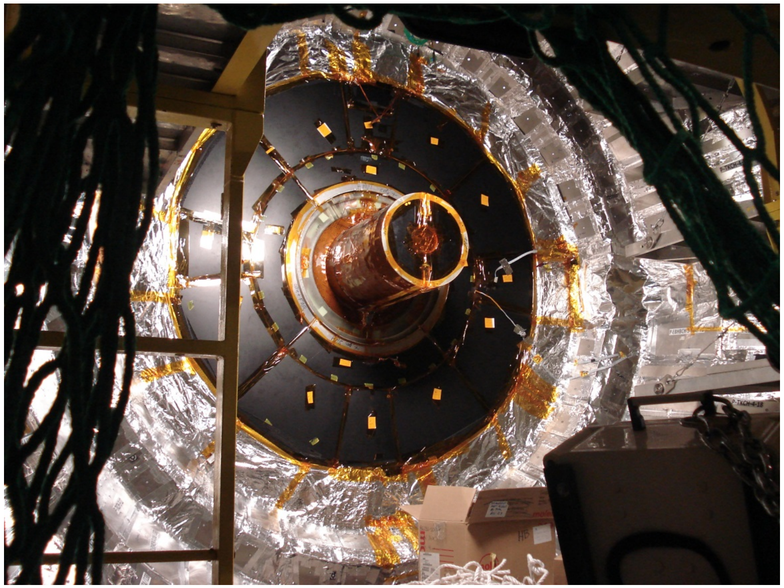
# Detector activities in LS1 (2013-2014)



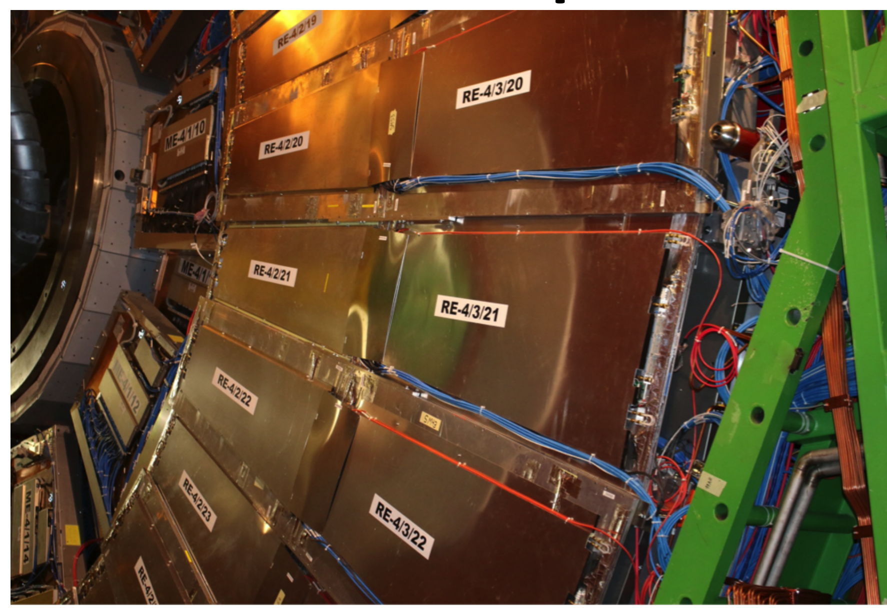
# LS1: on track getting ready for Run 2

**Tracker cold: tested -20$^0$C (Strips),-25$^0$C (Pixel) OK !!**

**Operation at tested -15$^0$C**

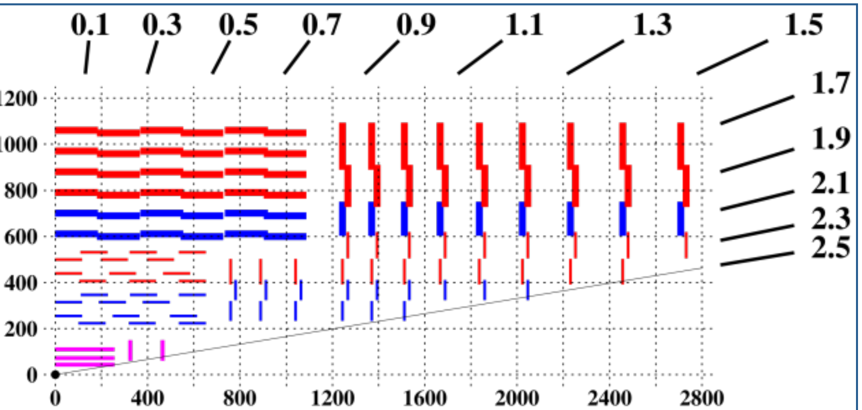


**RE4 construction (144 new RPC) and installation completed !!**

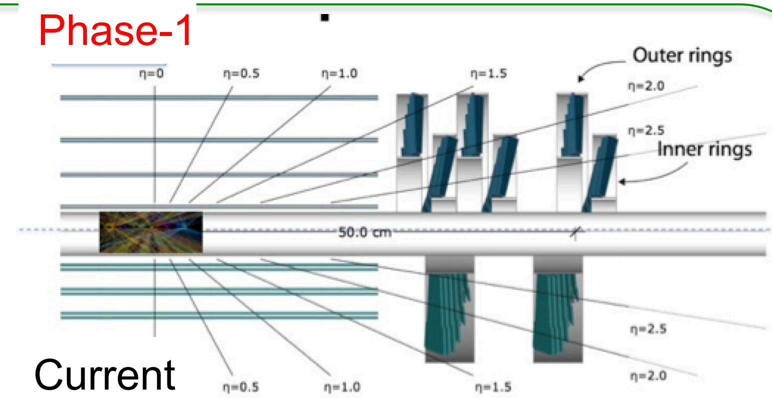



- **DT sector collector OK**
- **New beampipe OK**
- **Radiation shielding ready soon**
- **L1 trigger in progress**
- **New pixel to be installed end 2016…**

# From Current to Phase2 Tracker




CMS Si Tracker today




CMS **New Pixel Phase1** in 2017: all planar pixels

**Current & Phase1: Planar pixels**

**Strip/Strip modules SS**

**Outer Tracker, new Pt modules**

**3 more Pixelated layers**

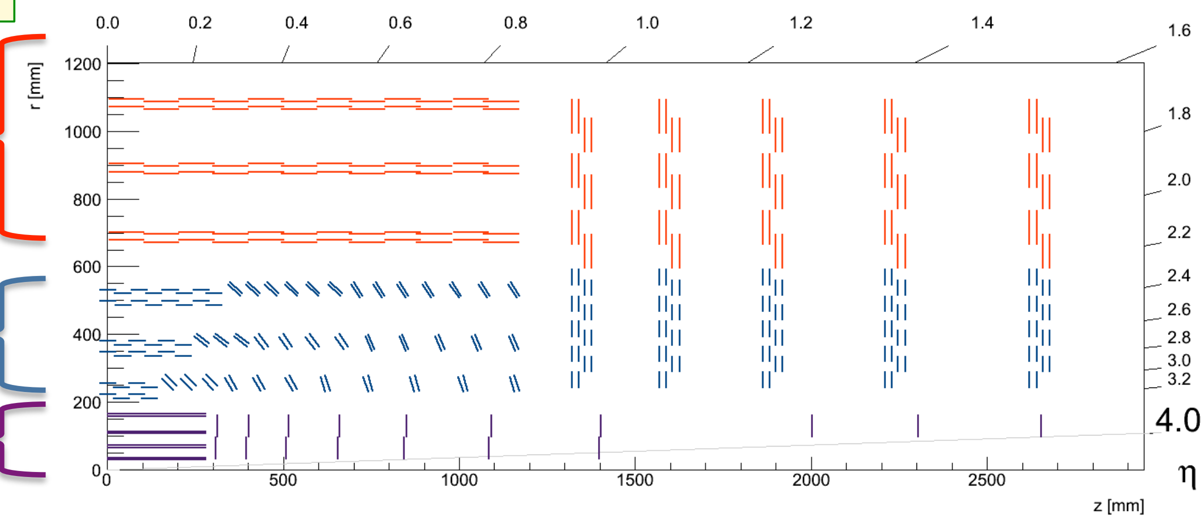
**5 more Pixelated disks**

**1.5x01.mm2 PLANAR pixel size**

**Strip/Pixel modules PS**

**Inner Tracker, new Disks to η=4**

**Pixel modules**




**Pixel Area 1.6m$^2$ Barrel + 2.0m$^2$ Disk**
**Possible pixel size ~25x100μm$^2$ ? Planar plus 1 or 2 layers 3D?**

**CMS Si Tracker as it could be in 2025**

# INFN Tracker R&D Phase2

## PIXELS

- **New pixel read-out chip 65 nm (ATLAS-CMS)**

  → CHIPX65 (call CSN5 2013)

  → CERN RD53

- **Sensors: 3D (ATLAS-CMS) and active-edge planar**
- Bump-bonding, test beam and irradiations are mandatory
- **Micro-cooling:** evaporating $CO_2$ finalized to CMS
  - R&D Planar Pixel: cost scale around 0.5 MCHF
    supported by Germany, Italy, Switzerland, Spain and US
  - R&D 3D Pixel: cost scale of the order of 0.5-1 MCHF
    supported by Italy, Germany, Spain and USA

## TRIGGER

- **Track trigger (ATLAS-CMS)**

# Pixel RO-chip R&D:
# CHIPIX65 (call CSN5 2013) + CERN RD53
# (CMS: BA, BG-PV, PD, PG, PI, TO and ATLAS: MI)

- **RD53 first general meeting April 2014 (schedule next slide)**
  - Strong impact of INFN groups (CHIPIX65) on several area:
  Radiation hardness, Analog-Front end, Digital architecture studies, IP-blocks
- **Milano joined RD53 (already in CHIPIX65)**
- **Delay in CERN / TSMC 65nm contract : impact on all RD53 submissions**
  - INFN submission (pixel matrix + IP-block) moved to Fall 2014 [Area: ~(3x4)$mm^2$]
- **Memorandum of Understanding almost ready** (signature for June-July)

- **INFN / CHIPIX65 will submit designs on silicon to the foundry via MPW:**
  - Small pixel matrix for studies of Very Front End analog designs
    - Synchronous and Asynchronous comparator;
    - Synchronous and Asynchronous FE
  - IP-block prototypes

Pixel matrix PUC dimension 50 um x50 um as agreed in RD53, few details to be discussed.

**CHIPIX65: Total 10-15 FTE**
**RD53: 100 members (50% designers)**

# RD53 Global Schedule as today

- **2014:**
  - **Release of CERN 65nm design kit: Very soon !**
  - Detailed understanding of radiation effects in 65nm
    - Radiation test of few alternative technologies (backup solution).
  - IP block responsibilities defined and appearance of first FE and IP designs/prototypes
  - Simulation framework with realistic hit generation and auto-verification.
  - Alternative architectures defined and efforts to simulate and compare these defined
  - **Common MPW submission 1: First versions of IP blocks and analog FEs**
- **2015:**
  - Common MPW submission 2: Near final versions of IP blocks and FEs.
  - Final versions of IP blocks and FEs: Tested prototypes, documentation, simulation, etc
  - IO interface of pixel chip defined in detail
  - **Global architecture defined and extensively simulated**
  - Common MPW submission 3: Final IPs and Fes, Small pixel array(s)
- **2016:**
  - **Common engineering run: Full sized pixel array chip**
  - Pixel chip tests, radiation tests, beam tests
- **2017:**
  - **Separate or common ATLAS – CMS final pixel chip submissions.**

# Pixel sensors R&D

# (CMS: BA, FI, MIB, PG, PI, TO)

## TOTAL CMS FTE 10-15


- **Joint R&D ATLAS_CMS**
  **➔ strongly supported by CERN**

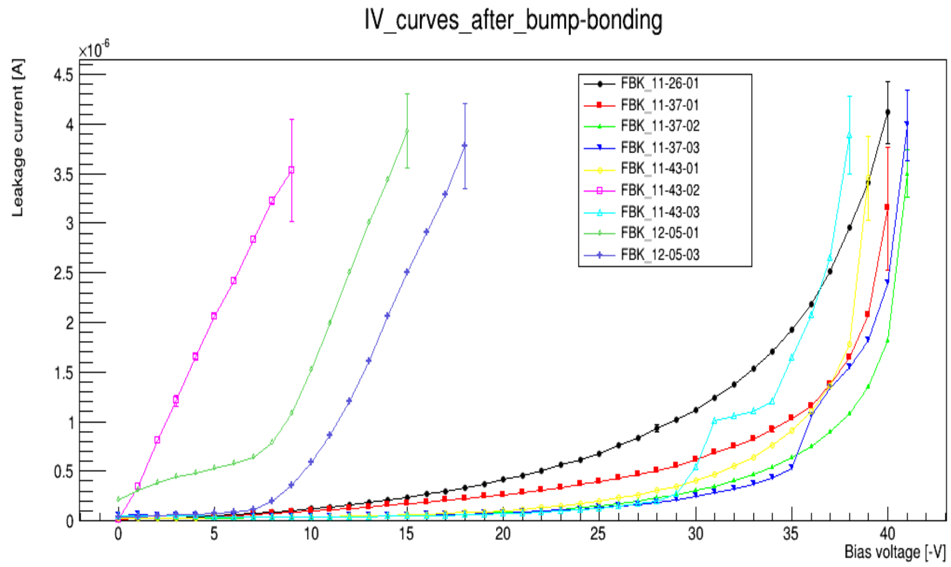
- **CMS PLAN:**
  - Design of 3D (with ATLAS) and planar pixel sensors: join development with FBK. Also comon CMS batches
  - Irradiation: 3 steps up to a $2x10^{16}$ Neq
  - Test Beam
  - Micro Channel Cooling: system with evaporative $CO_2$ to be verified in CMS

# Testbeam at FNAL: FBK 3D – May 2014

7 detectors 1E from ATLAS11 FBK production + psi46dig

Characterization and calibration in Torino lab. DAC registers exported to FNAL testbeam.

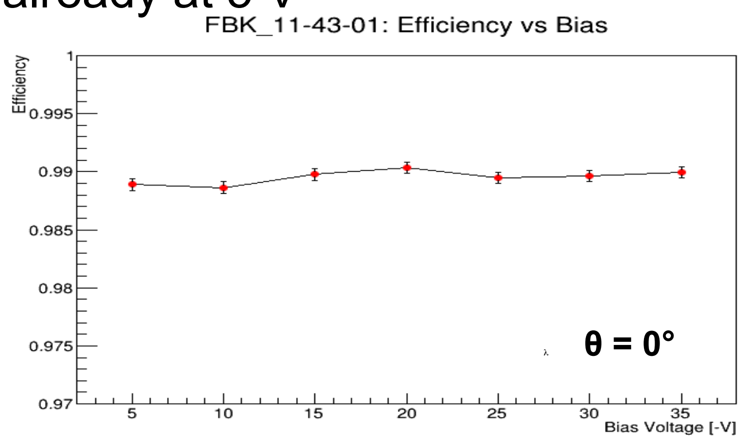
Testbeam analysis ongoing



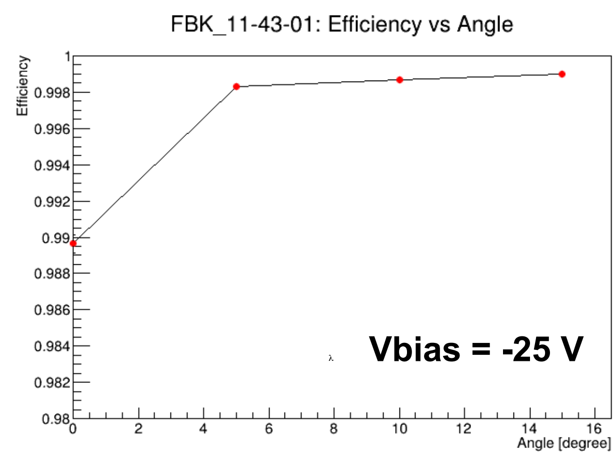

**Preliminary Results:**

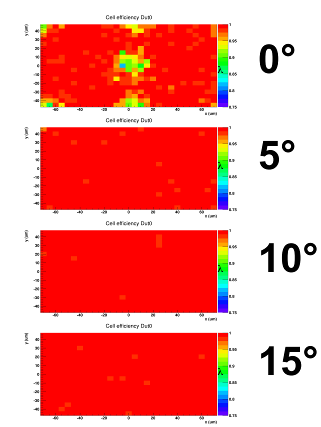
Threshold ~ 2700 e-

Full efficiency at 0° angle (>98,5%) already at 5 V




Angle scan: Electrode geometrical inefficiency already recovered at 5° (efficiency > 99,5%)



# Milestones & Deliverables

- Milestones defined for each R&D item
- Deliverables set according to milestones
- Milestone/Deliverables in common ATLAS/CMS for
  - Sensor production
  - QA/Irradiation/Beam Test of items in sharing

## Sensor Production

| Date | Milestones |
|---|---|
| (a)Year1-Q2 | $1^{st}$ planar batch Layout release (ATLAS+CMS) |
| (b)Year1-Q4 | $1^{st}$ 3D batch Layout release (ATLAS+CMS) |
| (c)Year2-Q1 | $2^{nd}$ planar batch Layout release |
| (d)Year2-Q4 | $2^{nd}$ 3D batch Layout release (ATLAS+CMS) |
| (e)Year3-Q2 | $3^{rd}$ planar batch Layout release |

## QA Irradiation and Beam Test

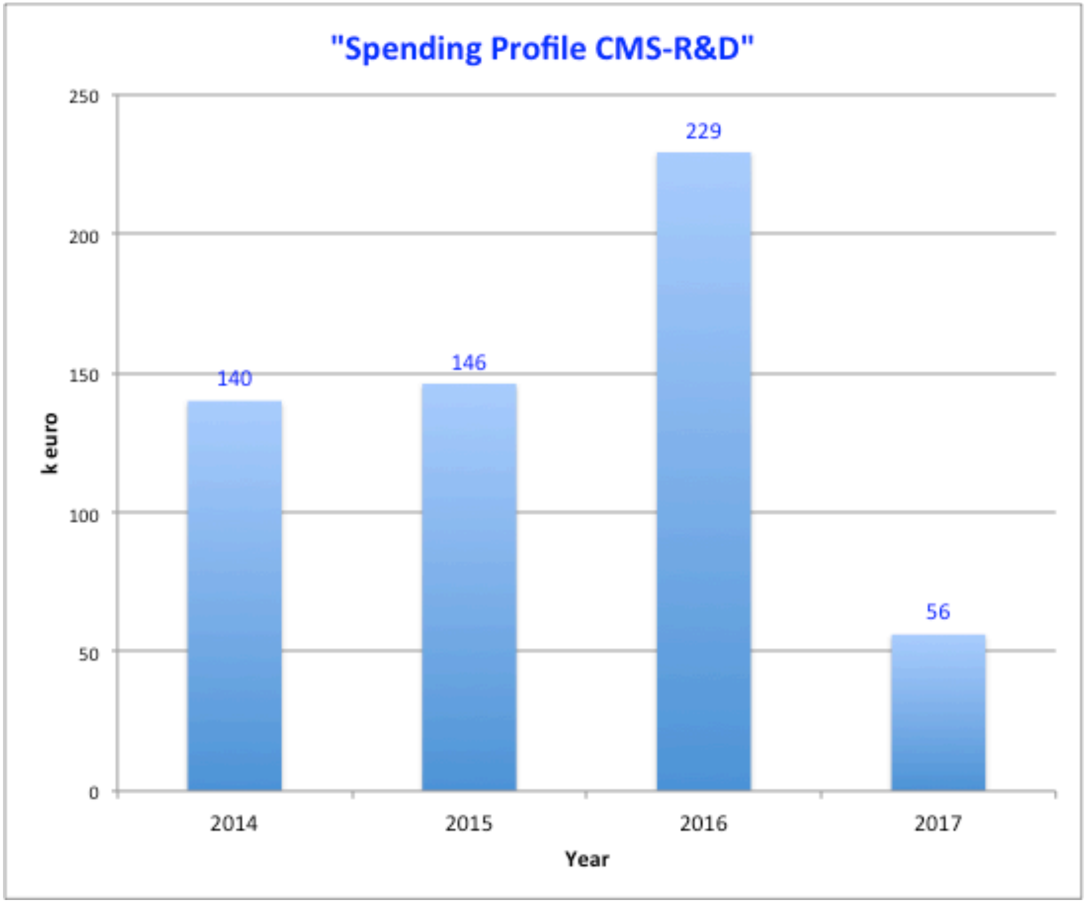
| Date | Milestones |
|---|---|
| (f)Year1-Q4 | DA & Software Ready for Beam |
| (g)Year2-Q4 | $1^{st}$ Batch of Planar Pixels Irradiated & Tested on Beam |
| (h)Year3-Q2 | $1^{st}$ Batch of 3D Pixels Irradiated & Tested on Beam |
| (i)Year3-Q4 | $2^{nd}$ Batch of Planar Pixels Irradiated & Tested on Beam |
| (l)Year4-Q2 | $2^{nd}$ Batch of 3D Pixels + $3^{rd}$ Planar Pixel Irradiated & Tested on Beam |

## Micro-channel cooling

| Date | Milestones |
|---|---|
| (l)Year1-Q3 | Cooling technology plan and simulation results |
| (m)Year2-Q2 | CO2 phase transition in micro-channel |
| (n)Year3-Q1 | Implementation of CO2 cooling in CFRP |
| (o)Year3-Q4 | Optimization of CFRP micro-channel tubes |
| (p)Year4-Q2 | Optimized prototype design |

| | FROM Kick-off | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Year1 | | | | Year2 | | | | Year3 | | | | Year4 | |
| | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 |
| Sensors | M-(a) | | | M-(b) | M-(c) | | | M-(d) | | M-(e) | | | | |
| QA/Irr/TB | | | | M-(f) | | | | M(g) | | M-(h) | | M(i) | | M-(l) |
| Cooling | | | M-(m) | | | M-(n) | | | M-(o) | | | M-(p) | | M-(q) |

# Spending Profile 2014-2017



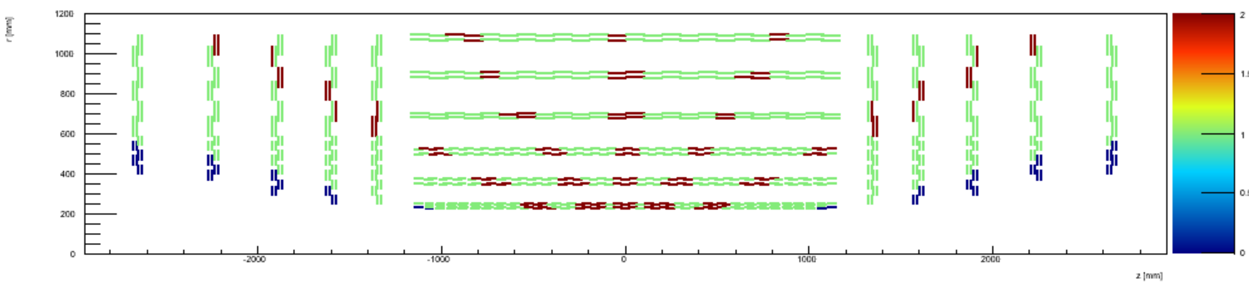

## CMS-R&D 572k€

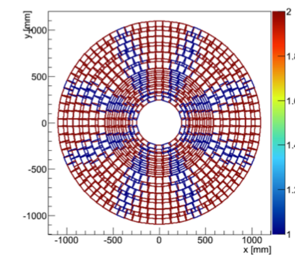
| | |
|---|---|
| Cost Summary | 572 |
| | |
| Sensors | 194 |
| Bump Bond | 203 |
| Test & Assembly | 50 |
| Irrad & Test Beam | 65 |
| Micro cooling | 60 |

Costs of "common" activities with ATLAS 204k€

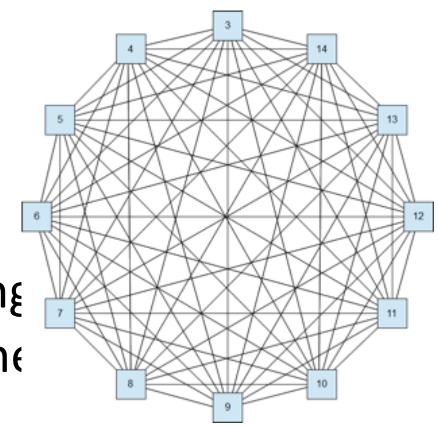
# CMS L1 Track Trigger approach

- Subdivide tracker into trigger towers
- 8(r-φ)x6(r-z) trigger sectors (some 10% overlapping)
  - Each sector ~200 stubs on average; tails up to ~500 stubs/event in 140 evts pileup+ttbar
    - About 600 Gb/s per one trigger tower




- Send data to Track-finding processors
- Full mesh ATCA shelfs
  - “40G” full-mesh backplane on 14 slots = 7.2 Tb/s
  - time multiplexing data transfer from a set of receiving boards to pattern recognition and track finding engine
  - O(10) time multiplexed at the shelf level



# Track Trigger: FLAM 2014-2018 (FI, LNF, MI, PD, PG, PI, SI, TS)

- feasibility studies of a L1 track-trigger with existing technologies, especially in the field of high bandwidth communication, both ATLAS and CMS
- development of beyond the state-of-the-art technologies for Associative Memory chips, both ATLAS and CMS

The proposed R&D is a significant advancement over the state of the art of the FTK processor with innovative content, especially in the design of a full-ATCA based processor and the realization of a System-in-Package that is a first (or early) use case at INFN and in the HEP community.

- Four Work Packages have been identified to deploy the R&D:
  - WP1: Simulation and Physics studies
  - WP2: High bandwidth communication
  - WP3: New generation Associative Memory chip
  - WP4: Packaging technologies

**Total FTE 13.3 (ATLAS 4.0, CMS 9.3)**

# FLAM Work-packges and costs

1. L1 simulation studies
2. Development of a "system demonstrator" based on full-mesh ATCA and AM chip technology
   - Develop a viable solution to L1 Track trigger architecture, and support the ATLAS and CMS Trackers design choice

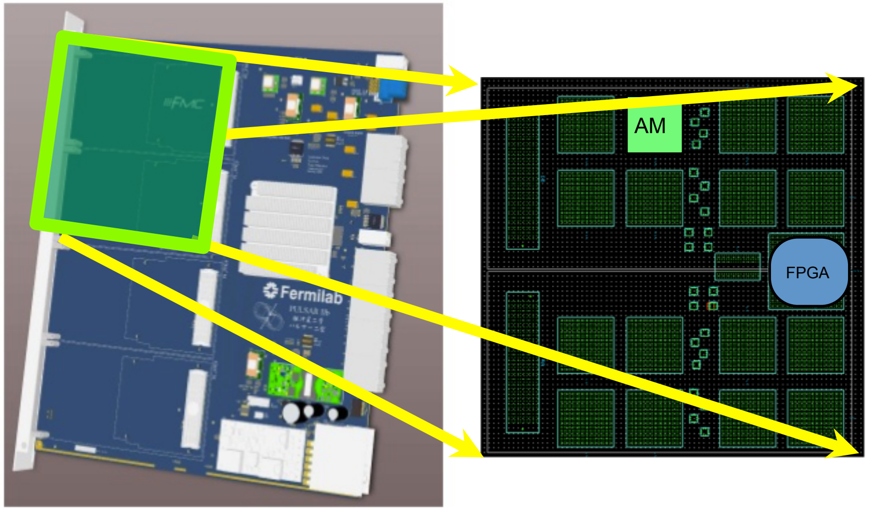
   Timeline for CMS and ATLAS TDRs ~2017
3. New generation AM chip
   - Increase pattern bank density, speed and lower the power consumption
     - Use "best foreseeable technology" for HL-LHC
4. System on Chip – Packaging AM + FPGA
   - Reduce trigger latency by including in the same package the new AM chip and FPGA – ideally 1:1

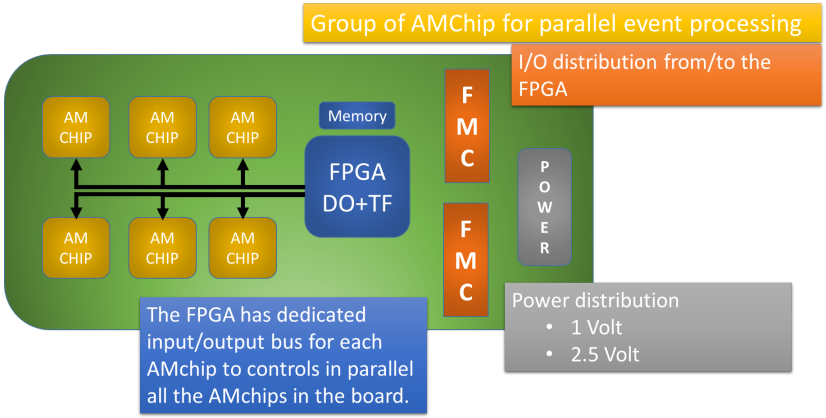
***PROJECT TIMELINE AND COSTS***

| WP | No. | Activity | Date | Cost (k€) |
|---|---|---|---|---|
| **1** | 1.1 | System simulation in Verilog/SystemC | 2014-17 | |
| | 1.2 | Development of physics algorithms and study impacts on the system | 2014-17 | |
| **2** | 2.1 | Development of a FMC mezzanine | 2014 | **20** |
| | 2.2 | ATCA test-stands | 2015 | **16** |
| | | | 2016 | **16** |
| | 2.3 | Pulsars and AMchips per test-stands | 2015 | **26** |
| | | | 2016 | **26** |
| | 2.4 | First demo stand running | 2015 | |
| | 2.5 | Final test with AM06 | 2016 | |
| | 2.6 | Test with AMSIP | 2018 | |
| **3** | 3.1 | Miniasic design | 2015 | **46** |
| | 3.2 | Miniasic submission and test | 2016 | |
| | 3.3 | Design and submission of MPW for AMSIP | 2016 | **90** |
| | 4.4 | Test MPW | 2017 | |
| **4** | 4.1 | Naked FPGA | 2017 | **50** |
| | 4.2 | Submission of multipackaging (AMSIP) | 2017 | **150** |
| | 4.3 | Mezzanine with AMSIP | 2018 | **10** |
| **Total cost (k€)** | | | | **450** |

# AM INFN Mezzanine (the heart)

- **A double FMC mezzanine to be mounted on Pulsar IIb (FNAL)**
  - Could work with (up to)
    - 16 AM05 chips (48 Kpatterns)
    - 10 AM06 chips (1.28 Mpatterns) due to power limitations
  - FPGA: Kintex7
    - 1440 DSP (for PCA fit)
    - 3 MB internal memory
  - Additional memory (72 MB)



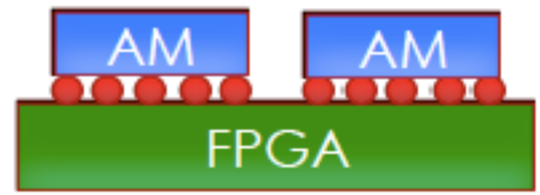

## Design of PCB finalized

**ready to order in 2014 ➔ 20 keu**

# Future progress: WP 3-4

## FTK could become smaller and smaller
## Multi-packaging FPGA & AMchip – mini FTK

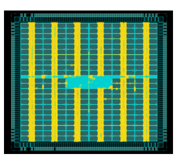
**WP4 (FPGA+AM chip) adatto per un FIRB**




**1 AM chip**
**1 FPGA in the same package**

**R&D coordinated with Fermilab**

**AMchip06 FTK**
**Design ends in 2014**



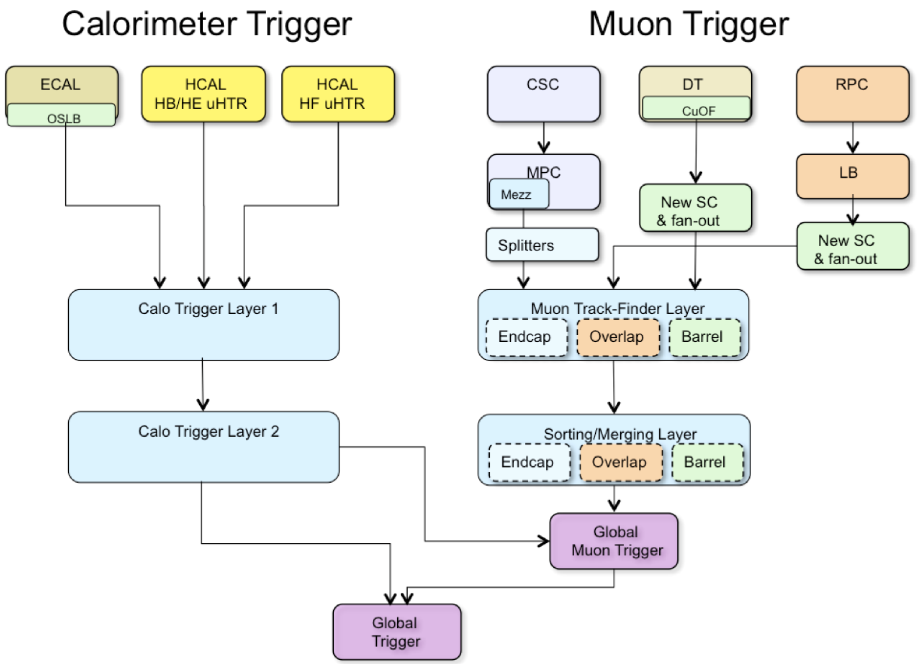
**Full custom AM cell**
**R&D limited by FTK schedule**

→ **Miniasic 40nm**
**~3mm$^2$**
**Cheap AM cell R&D**
**2015-16**

→ **MPW 40nm**
**~12mm$^2$**
**usable for ATCA demonstrator & system in package**
**2016-17**

**New Amchip:** 28 or 40 nm (200+ MHz?, new functionalities for L1)
Considering also 28 nm technology with similar budget for MPW (half minimum area)

# Trigger Phase1 & 2

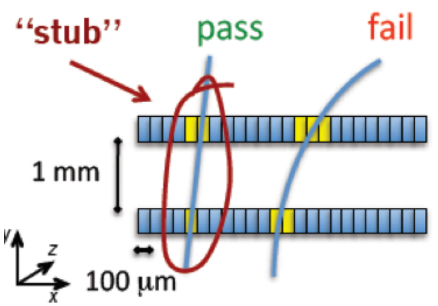



From year 2016, all the muon data will be used in a unique algorithm in order to have more robust system in the view of the lumi/ background increment planned.

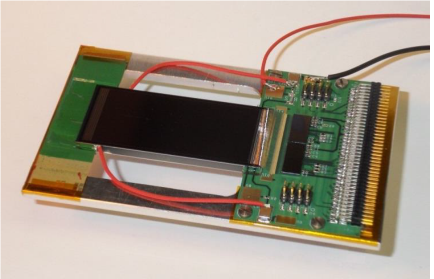
**Increase L1 Trigger rate from 100 kHz to 500 kHz … 1 MHz**

**Increase L1 Trigger latency from 4 μs to 10 μs**

the upgraded silicon strip tracker is being designed with triggering capabilities: layers are composed by pair of modules …



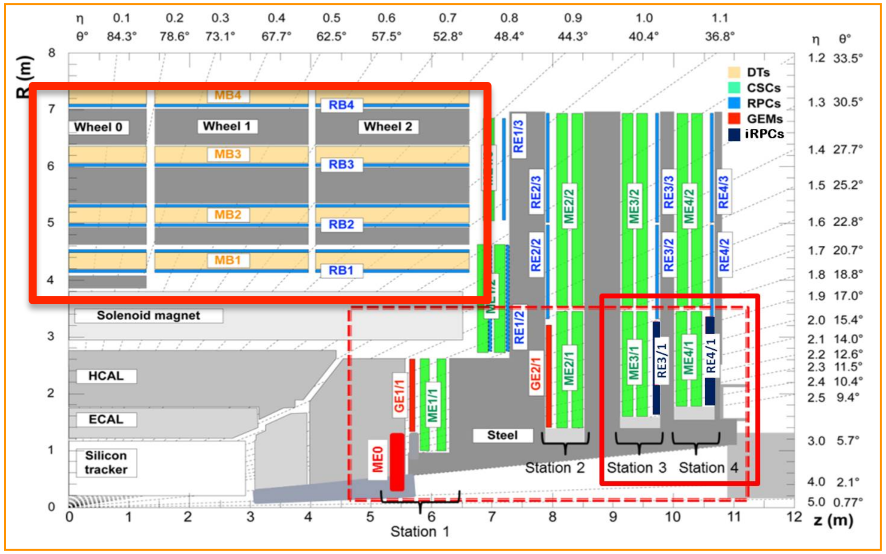

2 prototypes tested at DESY - 2 CBC chips - FPGA emulation of concentrator and of GBT on GLIB prototype DAQ board – validated trigger concept





All Outer Tracker modules are trigger modules

# Phase 2 Muon system

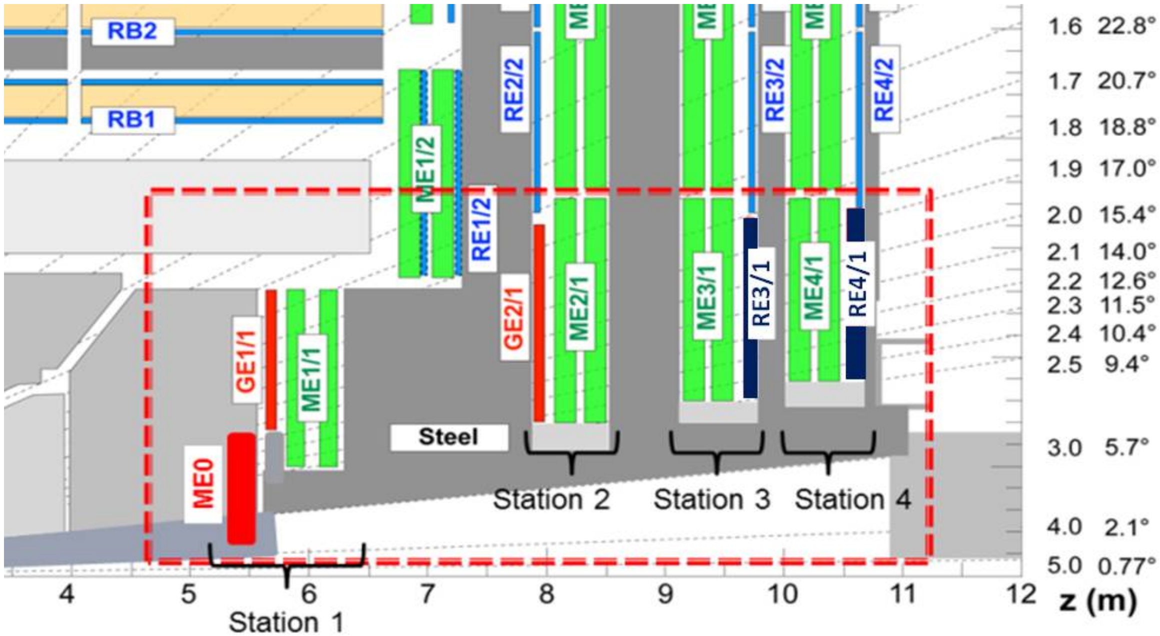



At present:
**Barrel muon system** covered with:
8 layers of chambers (58 hits max)
**Endcap region** covered with:
8 layers (28 hits max)
**High eta region** covered with:
4 layers (24 hits max)

- **Existing detectors worked very well**: large investment to be protected
  - All types of chambers (RPC, CSC, DT, GEM**) to be tested for aging at**
    **5x higher rates/6x higher doses in the GIF++ facility starting early 2015**

  must continue to operate without significant degradation → **consolidation**
- **Barrel DT minicrates replacement**: obsolescence of ASICs and new L1 trigger, improved trigger performance
- **Muon enhancements in forward 1.6<|η|<2.4 region**
  for redundancy and trigger: addition of small GEM and RPC in all four stations
- **Extension to the far forward region |η|>2.4:** a single muon tagging station
- **Need to reduce global warming footprint**: RPC eco-friendly gas studies

# RPC (BA, LNF, NA, PV)




**RE3/1 & RE4/1**

proposed to cover very forward region

**$1.6 < |\eta| < 2.4$**

**144 chambers** (~ 1.5-2.0 $m^2$ area) for inner ring 1 of disks 3 and 4

Rate: **1-2 $kHz/cm^2$** ➔ **x5 limit tested for existing RPC**

Integrated charge: **1-2 $C/cm^2$ @ 3000 $fb^{-1}$**

**Background rejection and muon reconstruction at HL-LHC**

keep trigger performance and low ($p_T$<20 GeV) threshold without significant performance degradation

Constant trigger rate with $p_T$<20 GeV

# Joint ATLAS-CMS phase 2 R&D: 2014-17

***Operation:*** 1-2 kHz/cm$^2$ ; 1-2 C/cm$^2$ @3000 fb$^{-1}$ with improved time resolution (10-100) ps

**iRPC**

- **Large area, improved:**
  - **Thin gap**
  - **Multigap**
  - **High voltage connections**
  - **Gas distribution and inlet**
- **with HPL / glass electrodes:**
  - **Lower resistivity** materials
  - **Thinner electrodes** to be tested to improve the S/N ratio, the spatial resolution and to reduce the stress (HV working point) and the aging

**Total CMS FTE 5**

- construction of a small set of **reduced size prototypes** (thin, multi-gap, different resistivity...) for a maximum of 10 chambers to test in common (ATLAS/CMS)
- construction of **prototypes** that fit all the specific requirements of both experiments
- **Aging test on detectors and materials at GIF++ (** strong gamma-ray source, muon-beam, cosmics)
- **Beam test facility at Frascati:** rate, efficiency, time resolution, sensitivity to photons and neutron
- **Test of FE electronics (aging and SEE) at various facilities** (GIF++, Louvain, …)

  verify currently installed boards for 10-year equivalent dose at HL-LHC

# The Quest for ecogases: Search Process

**The European Community has limited the industrial production and use of gas mixtures with Global Warming Power > 150 (GWP($CO_2$))**

- Ecofriendly low GWP ODP
- Compatible with RPC materials, under discharge, in high-rad
- Physics Performance
- Tune readout electronics
- Candidate mix test at irradiation facilities

**Plan to measure all the detector response parameter** (time, charge spectrum, streamer separation, noise, efficiency, possibly drift velocity, etc)

**$C_2H_2F_4$ is the main component of the present RPC gas mixture:**

**GWP($C_2H_2F_4$) = 1430, GWP($SF_6$) = 23900, GWP($iC_2H_{10}$) = 3.3**

**$C_2H_2F_4$ and $SF_6$ are crucial to ensure a stable working point in avalanche mode**

Similar problem for $CF_4$ (GWP = 5800) used in GEMs for time resolution

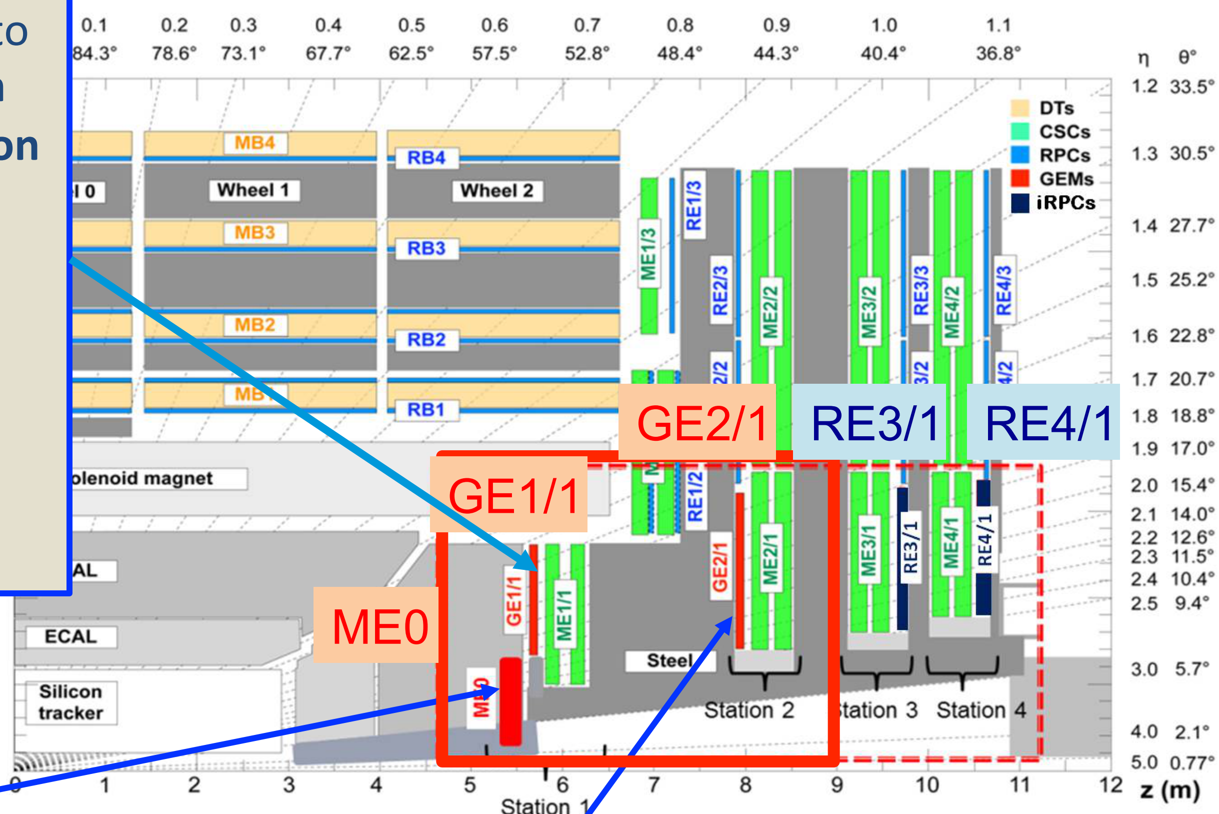
# GEM Upgrade project

## (BA, BO, LNF, NA, PV)

**Total: 10-19 FTE (2014-2017)**

### Phase1 LS2

- **GE1/1**: precision chambers to **improve trigger momentum selectivity and reconstruction** during late Phase1 and throughout Phase2
- Demonstrator in YETS2016 approved
- TDR by October 2014




### Phase2 LS3

- **ME0** module to **provide muon tag in highest eta region (eta=4)**
- Several tens of kHz expected → GEM
- R&D for ME0 launched

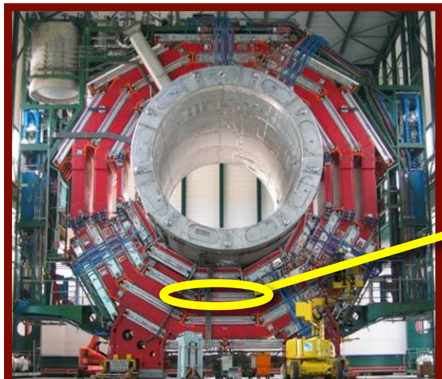
### Phase2 LS3

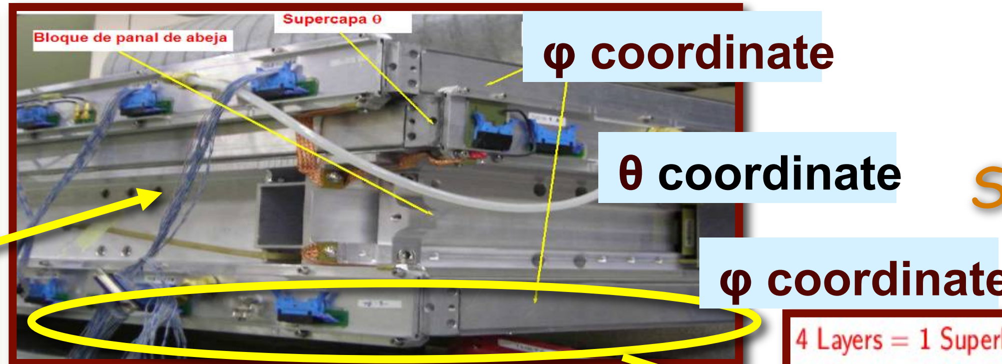
- **GE2/1:** 20 degrees precision chamber up to eta= **2.45** to **improve trigger momentum selectivity and reconstruction**

**In preparation: CALL CSN5 GEM (INTERDISCIPLINARY)**

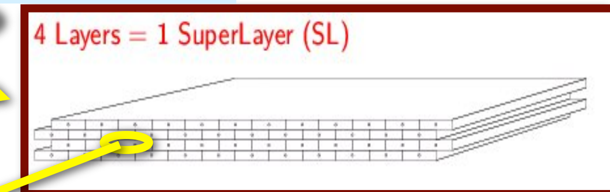
# 250 DT chambers + minicrates

# (50% INFN, 25% CIEMAT, 25% Aachen)

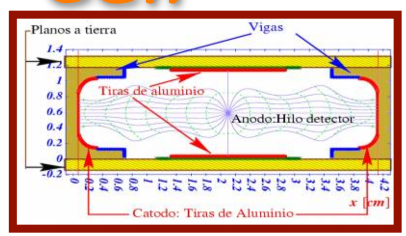


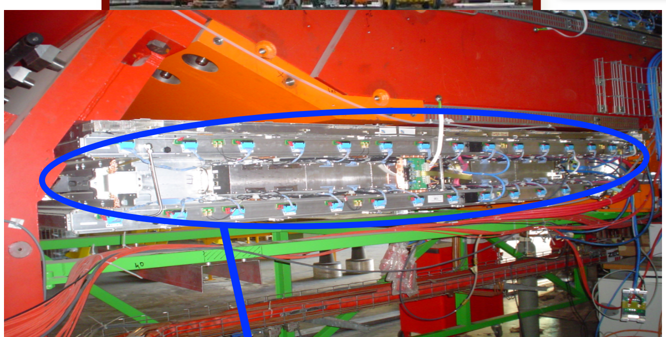


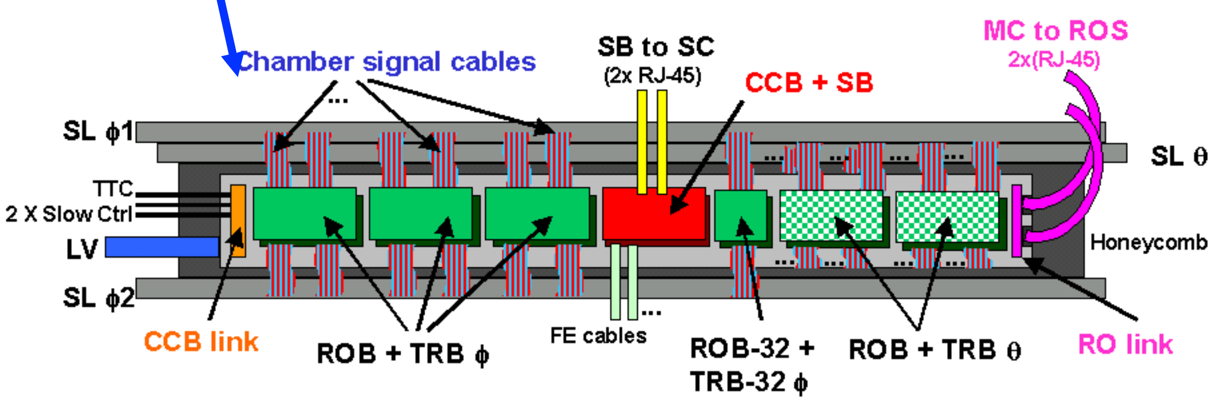

Superlayer




Cell



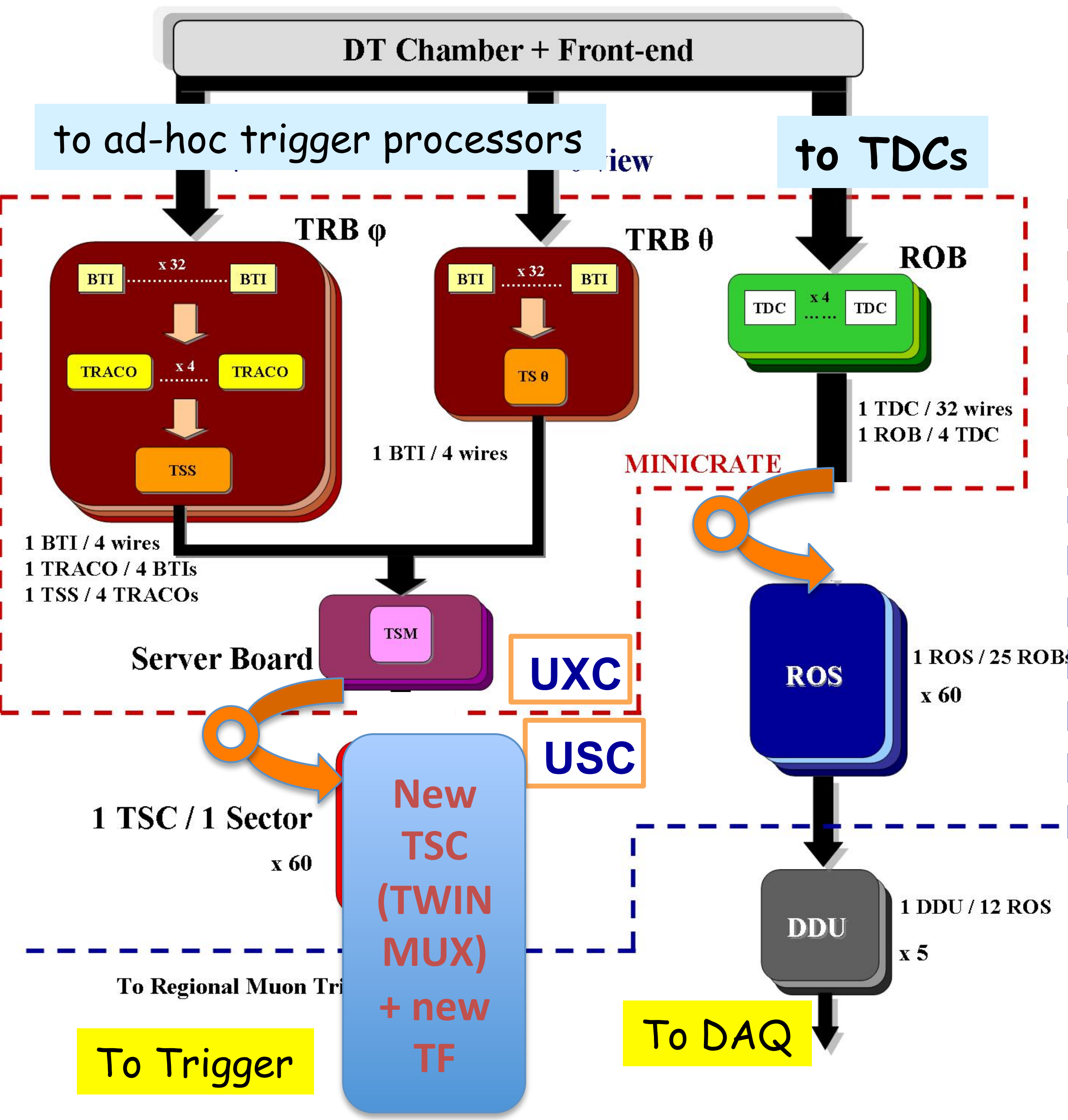






## a wonderful and unique detector:

Although based on drift tubes (drift time of 400 ns), it has proven from the very beginning to provide a **robust, efficient, pure trigger** with synchronization and **timing information with uncertainty below 1 ns**

# DT electronics for Phase 1




**Sector Collector moved to USC**

Second level of DT read-out and trigger

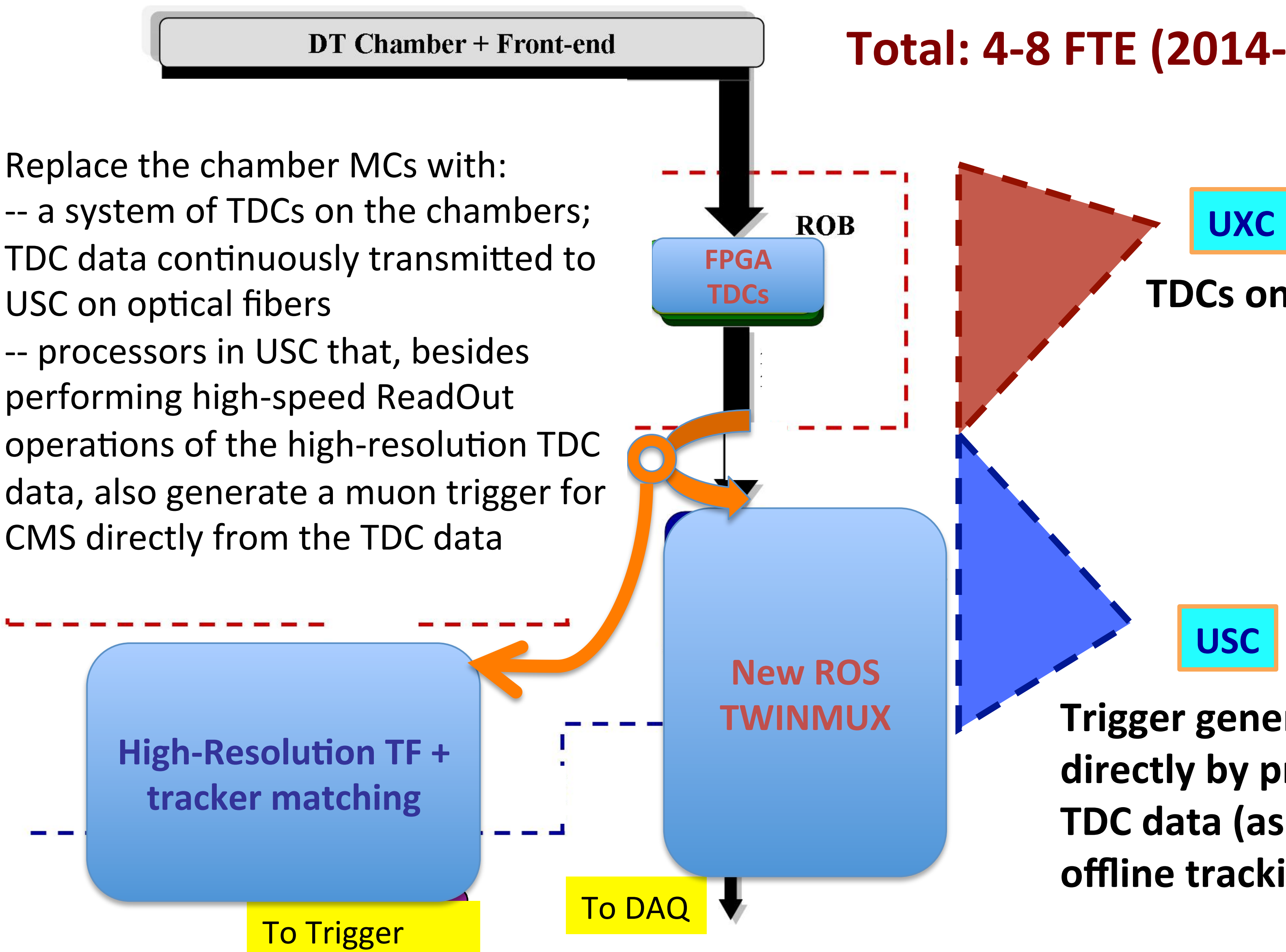
TWINMUX could have inputs also from RPC and HO. Improve rejection against low Pt.

**3500 optical links**

# DT electronics for Phase 2

**Total: 4-8 FTE (2014-2017)**

Replace the chamber MCs with:
-- a system of TDCs on the chambers; TDC data continuously transmitted to USC on optical fibers
-- processors in USC that, besides performing high-speed ReadOut operations of the high-resolution TDC data, also generate a muon trigger for CMS directly from the TDC data




**TDCs on chambers**

**Trigger generated directly by processing TDC data (as the HLT & offline tracking)**

# DT electronicsPhase 2

Project workplan is at a very early stage. However there exist time constraints driven by the LHC schedule:

**Installation of the new electronics planned for the Long Shutdown LS3 in 2024**

**2020/21 until LS3: 4 years construction**

R&D phase

- ✓ 2015/16: study and discuss overall architecture.
- ✓ Until LS2 in 2019/20: Development of the physical components, testing and system prototyping, with the new-minicrate electronics and new USC electronics being developed in parallel.

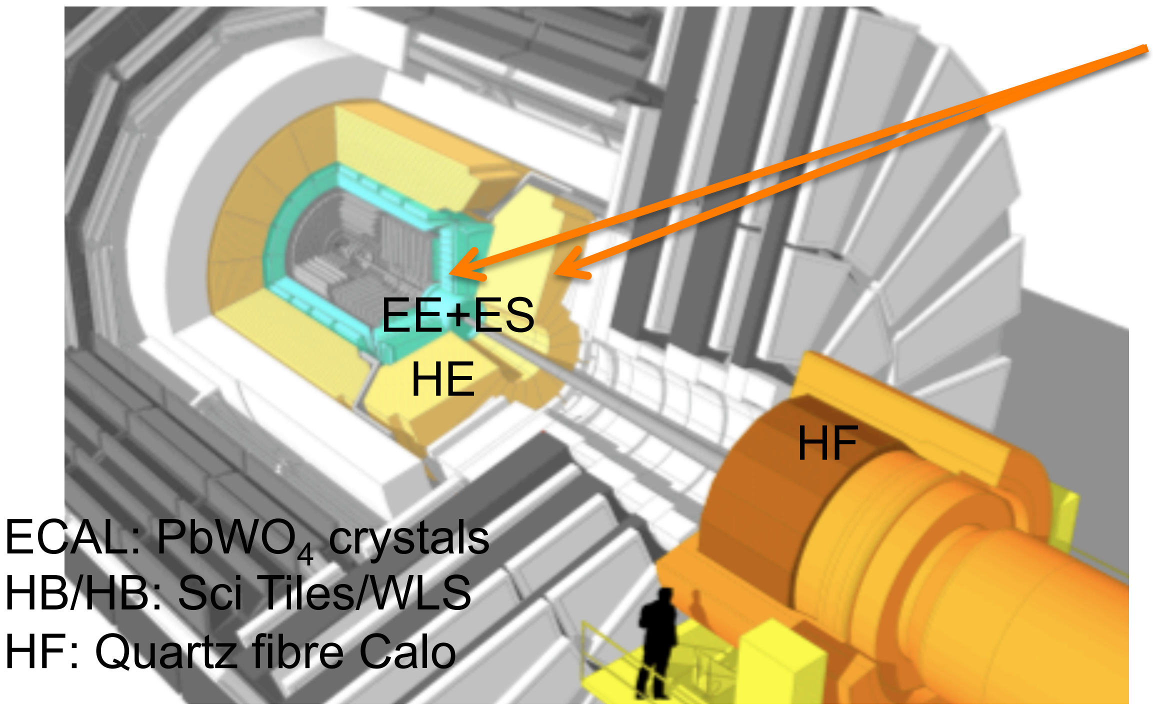
**Strategy:** design based on commercial hardware of CMS-wide use

**Innovative aspects are in the firmware**:

- A high-performanceTDCs algorithm, developed and implemented in radiation tolerant FPGAs, in collaboration with CIEMAT
- A hit detection and track fitting algorithm for processing the TDC data and generate a trigger primitive, to be developed and implemented in FPGAs.

# Endcap calorimeters: longevity appraisal and upgrade plan

- *Substantial* performance degradation in the ECAL and HCAL endcaps
- *Moderate* damage in the ECAL and HCAL barrel
  - Increase of APD dark current in ECAL will require mitigation
- Moderate degradation in HF (operable throughout Phase II)

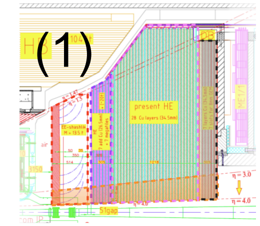



- **Replacement/upgrade of both ECAL and HCAL endcaps in LS3**
- **Upgrade of the ECAL FE electronics: 40 MHz data stream (barrel)**
  - HCAL upgrade in LS2
- ***Possible*** mitigation of the APD current noise
  - VFE with faster shaping time (also, improved timing, spike rejection)
  - Cooling of the barrel

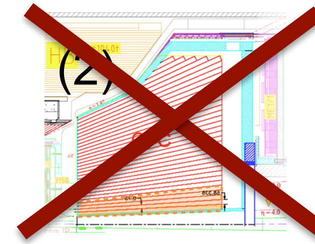
# Endcap calorimeter options

- Down-selection from 3 to 2 at the beginning of April 2014

1) **Maintain current structure**
   - **Replace ECAL and refurbish HCAL with rad-hard technologies, improved compactness and granularity**
   - ***"Emphasis on photon reconstruction"***

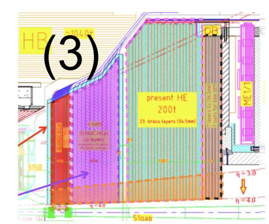



2) ~~**Merge EM and HAD compartments into a (rad-hard) dual readout fibre calorimeter**~~
   - ~~***"Emphasis on jet resolution"***~~



3) **Finely segmented calorimeter**
   - **(600 m$^2$ silicon pads in W/Cu structure)**
   - ***"Readout as much information as possible"***

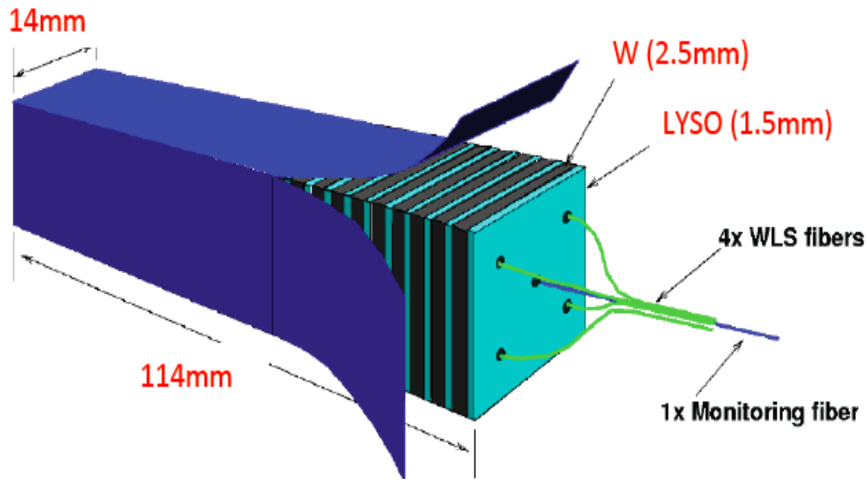
I WILL NOT DISCUSS OPTION 3) TODAY




- **R&D on fibres encouraged to continue**
  - **Vital WLS component for option 1)**
  - **Provide alternative solutions to option 1)**

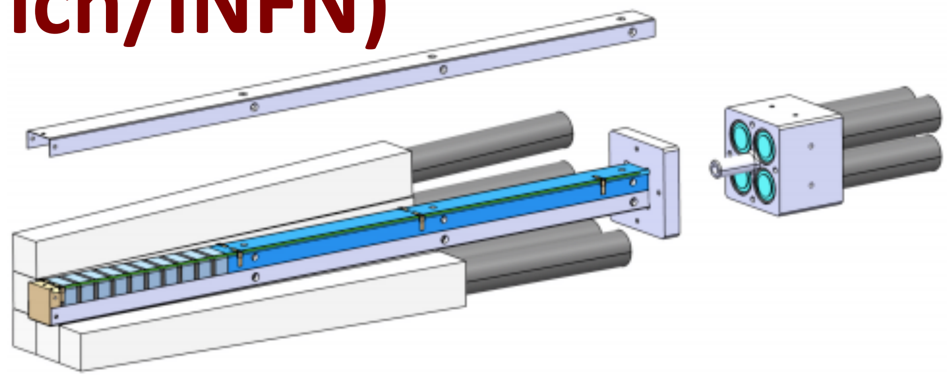
# EM endcap calorimeter with optical readout

- Main features
  - **LYSO / W** (**or $CeF_3$ / W**)
  - **Molière radius 1.4 cm** (2.2 cm in $PbWO_4$)
  - **Energy resolution ~12%/√E (+) 1%**
- Major challenges and R&Ds
  - **Rad-hard WLS fibre**
    - Capillary with WLS liquid
    - $SiO_2$:Ce matches $CeF_3$ emission spectrum
  - **Photosensors:**
    - GaInP-PM on detector: very challenging
    - Si-PM at remote location (or cooled??)
    - Rad-hard PMTs
  - Crystal production (and rad-hardness)
- Cost drivers:
  - Crystals and readout



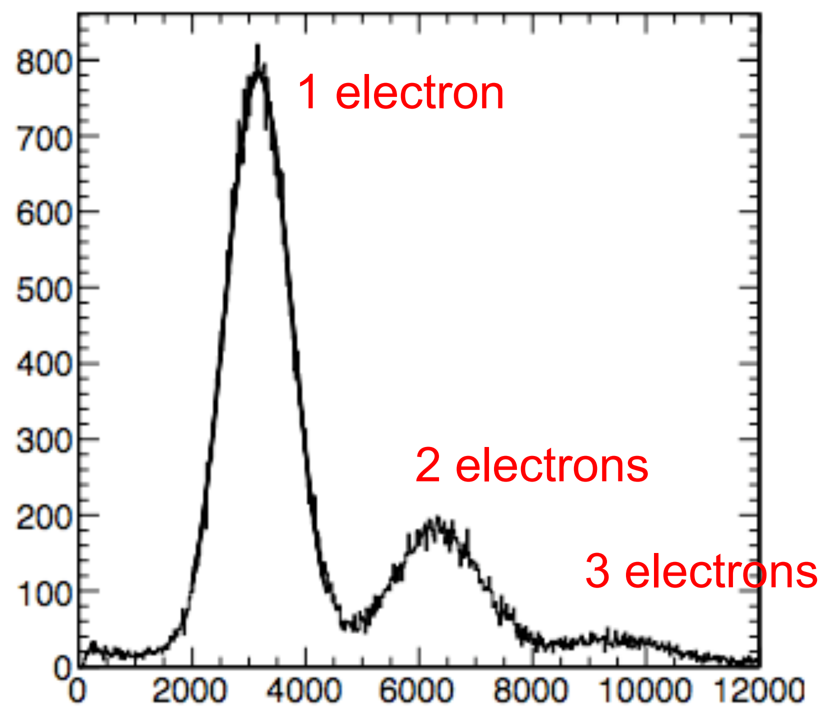

- Resolution comparable to current calorimeter
  - Stochastic term ~ 15%/√E
- Piluep resilience
  - Compact shower size (small Moliére radius) and fine transverse granularity
  - Fast response (and 50 ps timing capability)
- Tower structure to facilitate integration in the CMS reconstruction and trigger

# Test beam at LNF-BTF with $CeF_3$ - shashlik (ETH-Zurich/INFN)



- Central 2.4x2.4 $cm^2$ tower: 10 layers
  - 10 mm $CeF_3$ crystals / 3 mm W plates,
  - Kuraray plastic WLS fibres in the corners
    - Aim at testing SiO2:Ce
- Shower containment and additional setup
  - Matrix of 8 BGO crystals
  - Beam hodoscope with 1 mm pitch x-y for position scan

- Beam energy 500 MeV
  - Resolution ~12% @ 1 GeV
  - N p.e. ~ 200-300 / GeV




- Next at high energy beam (SPS) November 2014
  - Possibly with SiO2:Ce as WLS

# Alternative R&D opportunity: fibre calorimeter (spacal)

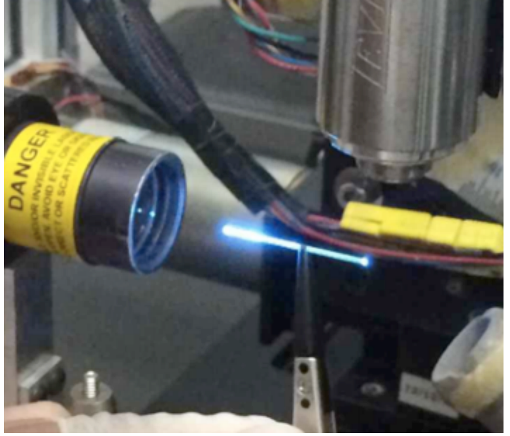
Parameterization::
$\sigma_E/E$ (samp) ~ 2.7% $\sqrt{(d/f_{samp}}$

| Absorber | ρ (g/cm³) | $f_{samp}$ | $\sigma_E^{samp}/E$ (%) | $X_0$ (cm) | $R_M$ (cm) |
|---|---|---|---|---|---|
| Cu | 7.64 | 0.068 | 9.26 | 1.87 | 2.0 |
| Pb | 9.56 | 0.054 | 10.35 | 0.71 | 2.2 |
| W:Cu (70:30) | 13.48 | 0.039 | 12.30 | 0.55 | 1.7 |
| W | 15.96 | 0.033 | 13.38 | 0.45 | 1.6 |

Table 1. Expectations for a quartz-fibre calorimeter; the sampling fraction $f_{samp}$ is given by the fibre to total mass ratio.

- Compactness and sampling term comparable to crystal shashlik
  - Transverse granularity virtually very high (defined by the readout pitch)
- R&D challenges
  - Photodetectors (common to Shashlik)
  - Radhad fibre with sufficient light output (at least 100 p.e./GeV for 10%/√E)
- Fibres as active medium provide *flexibility in the design* and potentially *lower costs* than calorimeters based on crystal or silicon as active media.

# R&D Plan for 2014-2016
## (MIB, RM1, TO, TS)




- BTF test beam on iMCP (CSN5 project MIB-RM1) now
- Replacement of the plastic fibres with SiO2:Ce fibres for WLS in the CeF3 shashlik
- Production of a single W/Cu tower 2.4x2.4 $cm^2$ to be tested in the BGO matrix
  - Need 1000 fibres with 0.8 mm diameter + mechanics
- Production of a full 3x3 prototype in W/Cu configurable (could host different type of fibres) to be tested in 2015
- Summary: 30 keu for prototyping in **2014**
- **2015-2016:**
  - ✓ Rad hard fibers R&D
  - ✓ Rad hard SiPM with FBK
  - ✓ Mechanical structure

**Total: 4-6 FTE (2014-2016)**

# CMS phase 2 R&D - summary

| R&D CMS FASE2 | | | sett 2013 | 2014 | TOTALE | ATL+CMS | ANNI | FTE | commento |
|---|---|---|---|---|---|---|---|---|---|
| TRACKER | PIXEL | sensori | | 64 | 194 | 1123 | 2014-2017 | 9-14 | include assegnazione CMS 0.5*65keu feb14 (ATLAS GE) |
| | | BB | | 27 | 185 | | | | |
| | | test | | 20 | 50 | | | | |
| | | irraggiamenti | | | 65 | | | | |
| | | microcooling | | 20 | 60 | | | | |
| | TRIGGER | track trigger | | 20 | 233 | 450 | 2014-2017 | 9.3 | |
| MUONI | RPC | elettrodi | | | 27 | 277 | 2015-2017 | 5 | |
| | | prototipi | | | 37 | | | | |
| | | FE | | | 32 | | | | |
| | | ecogas | | 5 | 18 | | | | |
| | | GIF,BTF, etc | | | 24 | | | | |
| | DT | irraggiamenti | | | 11 | 261 | 2015-2019 | 4-8 | |
| | | elettronica | | | 250 | | | | |
| | GEM | irraggiamenti | | 15 | | | 2015-2017 | 3.5 | nuova attivita' PV GE1/1 |
| | | prototipi | | | | | | | call interdisciplinare CSN5 |
| CALO | BARREL | irraggiamenti | 12 | | | | 2013-2014 | | invecchiamento APD |
| | | elettronica FE | | | | | 2016-2017 | | fase prototipi - studi in corso |
| | ENDCAP | fibre | 15 | 20 | 200-250 | 300 | 2014-2016 | 4.5 | |
| | | fotorivelatori | | | | | | | in fase di finalizzazione |
| | | meccanica | | 10 | | | | | |
| | | timing | 15 | | | | | | progetto finanziato CSN5 2014-15 |
| TOTALE | | | 42 | 201 | 1186 | 2411 | | | |

# External Funds and Resources

- **PRIN: H-TEAM:** MIUR 2014-2016 (321 keu) CMS+ATLAS 7 assegni biennali (uno per sede)
  Univ PI (atlas-cms), Univ TO (cms), Univ SI-FI (cms), INFN PG (CMS) - MI (atlas)

- **AIDA-1 program 2012-2015:** BA, BO, FE, GE, LNF, LE, MI, PD, PV, PG.PI, RM2

✓ irradiations of the CMS-HPK campaign
✓ .....
✓ ...

- **FP7-PEOPLE-ITN INFIERI:** art 23 da settembre 2014

- **AIDA-2 under construction:**

✓ 3D sensors and Pixel modules for HL-LHC upgrade of ATLAS and CMS
✓ Microelettronica
✓ iRPC on WG12 Gas detectors
  - 12.1.1 Ecogas (**Tor Vergata,** *Bari, LNF*, **...**)
  - 12.1.2 Electrodes (**Coimbra**, *Bari, LNF,...*)
  - 12.1.5 High rate and fine resolution RPC (**Tor Vergata**, *Bari*, ...)
  - 12.3.6 Standard production protocols of optimized RPC components for technology dissemination (**Bari**, *LNF, Coimbra,MPI,...*

✓ Optical read-out calorimeters on WG15: test benches for fibers characterization, photodetectors, irradiation, test beam and mechanical prototypes

# BONUS

# DT phase2 electronics workplan generalities

-- Although the architecture to be studied in 2015/16, an effort is going in CMS for estimating the total cost of the new DT electronics, based on today's HW with reasonable extrapolation factors. A first iteration cost table is being scrutinized.

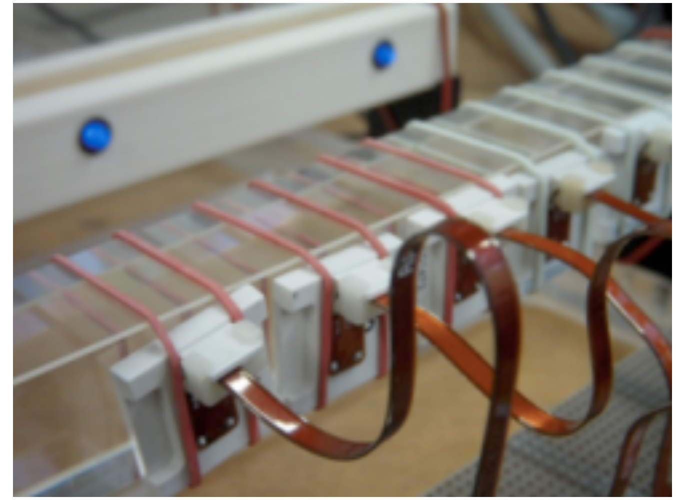
-- the R&D is based on today's HW. For the trigger R&D of INFN interest, a cost of 250 Keuro can be estimated from the cost of the basic items:

-- Microsemi and Xilinx FPGAs, optical links (GBT components, Versatile links), PCBs fabrication and components assembly (3 different boards will have to be produced, with 2 submissions each), aluminum extrusions, uTCA crates with PS and interface boards, high-end CMS uTCA cards, testing equipment (pattern units).

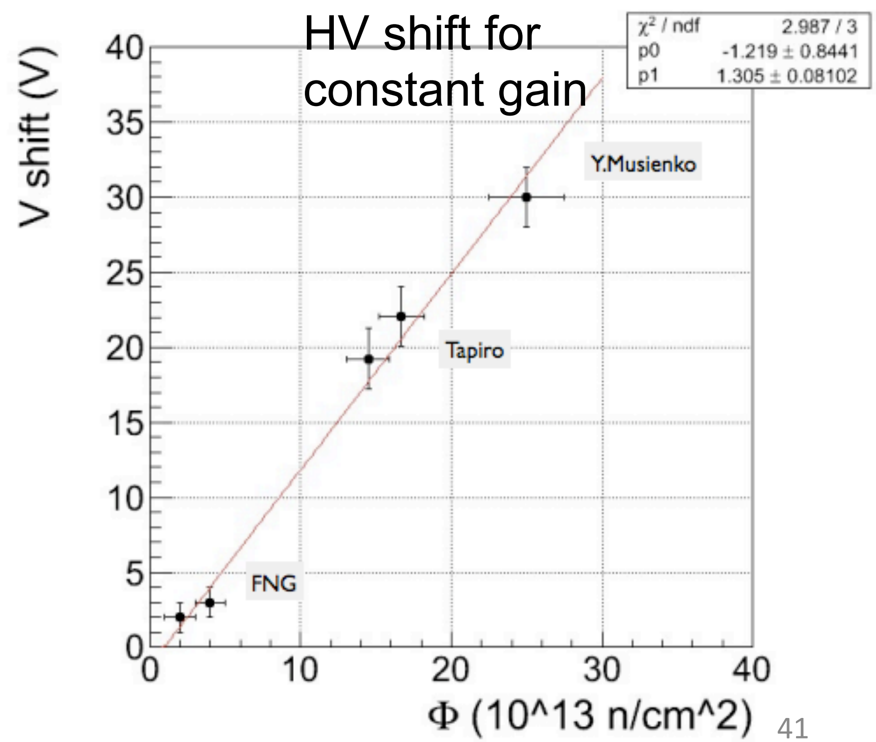
-- This is ~50% of the total R&D cost, and represents ~4% of the estimated total cost of the Drift-tubes Electronics upgrade for LHC Phase-2.

-- expenditure will start not earlier than 2016, after the study phase, and will cover until LS2 in 2019/20.

# Further appraisal of APD longevity ongoing



- Irradiation at neutron fluence $10^{13}$-$5x10^{14}$ $cm^{-2}$
  - 4 APDs at Frascati Neutron Generator: end of LHC phase I
  - 10 APDs at ENEA reactor Tapiro: mid of HL-LHC.
  - Further exposure next week: beyond 3000 $fb^{-1}$
- Test bench in Rome1
  - APDs still operable
  - Parameters for ECAL barrel cooling + faster shaping time (new VFE) to mitigate dark current being clarified



# GEM Background studies

PAVIA A. Magnani C. Riccardi P. Salvini I.Vai P.Vitulo, P. Montagna A. Braghieri

Testing GE1/1 and new MPGD at gamma, neutron irradiation facilities (GIF, Louvain, Upssala) to study the response of MPGD, necessary to understand their behavior and operation in presence of large backgrounds. Simulations with Geant4

Requirements: suitable flux, proper location taking into account the detector dimensions, gas, HV

Facilities: BTF (1 MeV) (possibly), Louvain la Neuve (BE) → neutrons up to 50 MeV (peak 20 MeV) (**2014**)

Uppsala (SE) → neutrons from 20 MeV up to 175 MeV (quasi monoenergetic beams) ( 2015), GIF (Cern) → 662 keV gammas (2015)

FUNDS: Irradiation at Louvain la Neuve (BE) 7kE

Setup → Mechanics for support + transports 2kE

10x10 cm2 prototype chamber 3kE

receiver boards and test readout setup 3kE

New

ME at Louvain (0.25mu x4) 4kE

ME at Cern in order to prepare the setup (0.25mu x4) 4kE

**Additional request total for 2014: 15kE + 8kE ME**