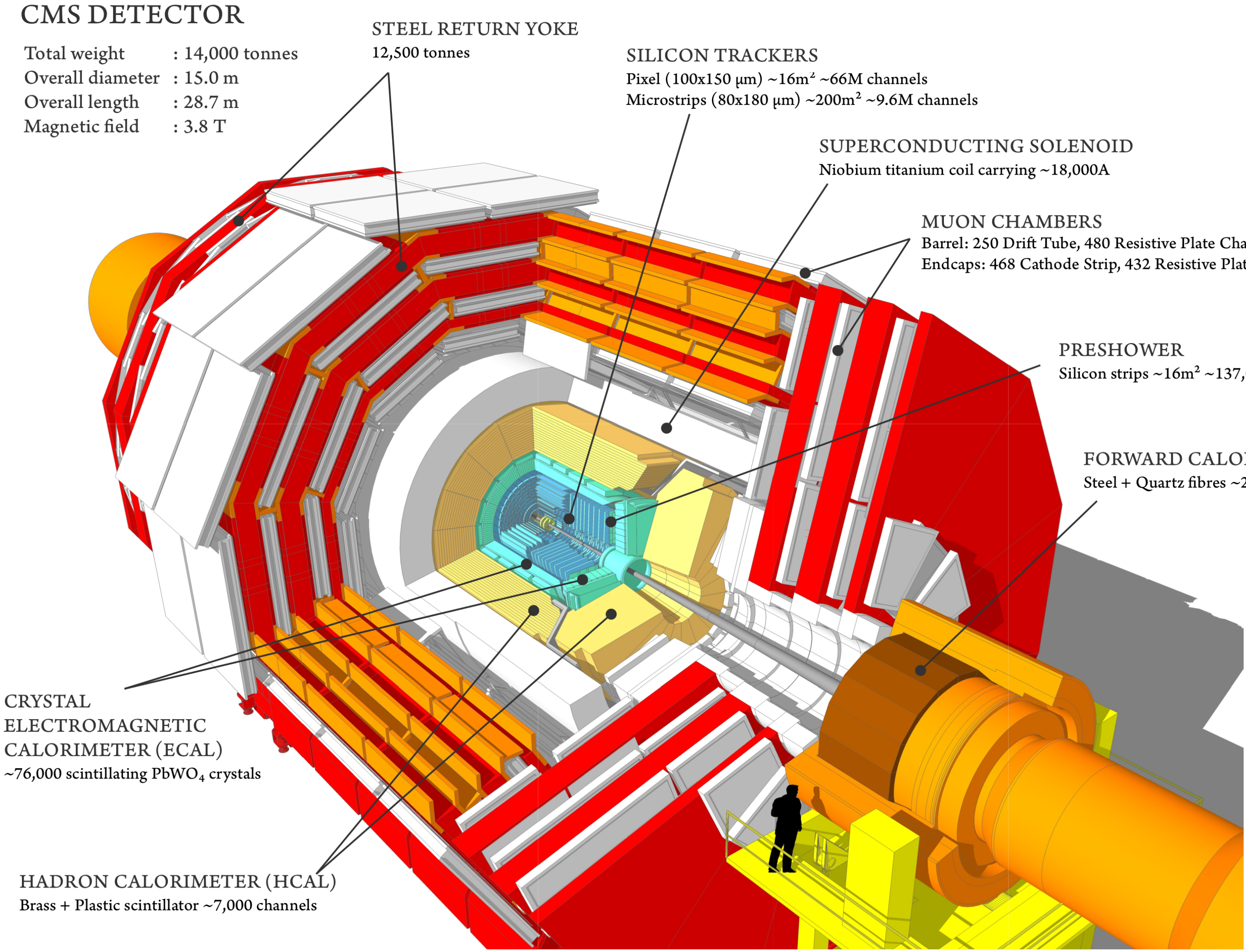
Overview of CMS Forward Muon Upgrade

Brian L. Dorney on behalf of the CMS Collaboration

The CMS Detector



CMS Collaboration, Lucas Taylor, "CMS detector design," http://cms.web.cern.ch/news/cms-detector-design 2011.

The CMS Trigger

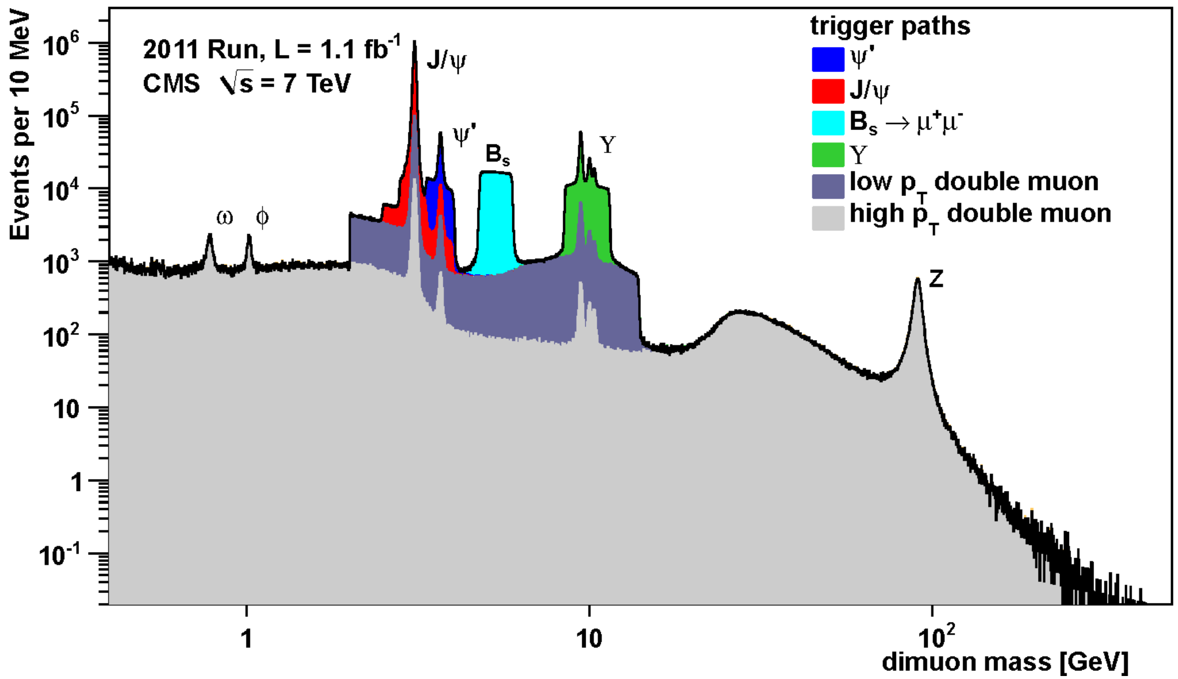
- Two level system
  - Hardware level: on-detector electronics, *Level 1* (L1)
  - Software level: underground CPU farm, *High Level Trigger* (HLT)

- Significant rate reduction
  - LHC collision rate is O(10 MHz)
  - L1 trigger readout rate ~100 kHz
  - HLT rate ~1 kHz

~400 different trigger paths select *pp* collision events for offline analysis

CMS Muon Performance: Run I

- Muon-trigger demonstrated superb performance over very wide p_T range!

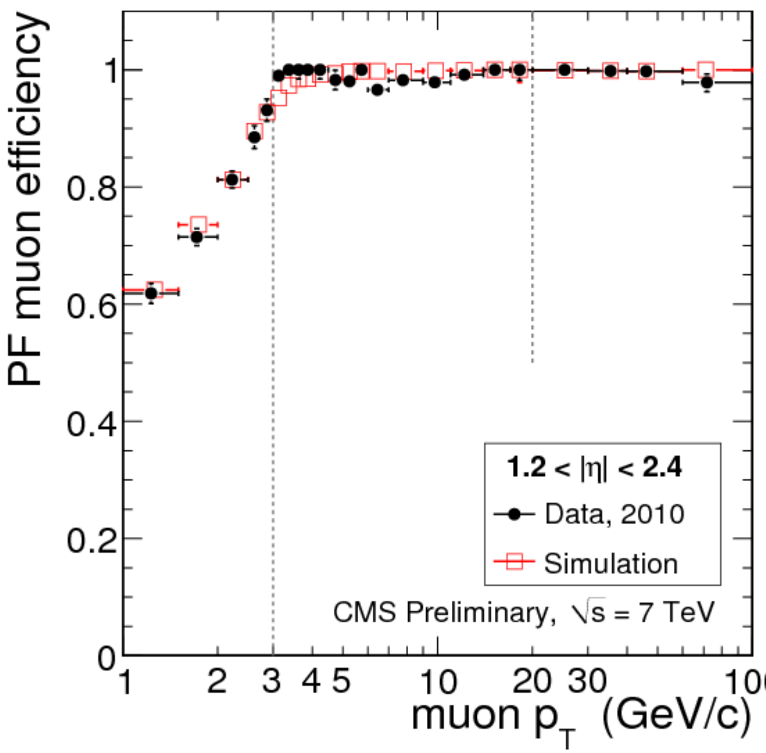


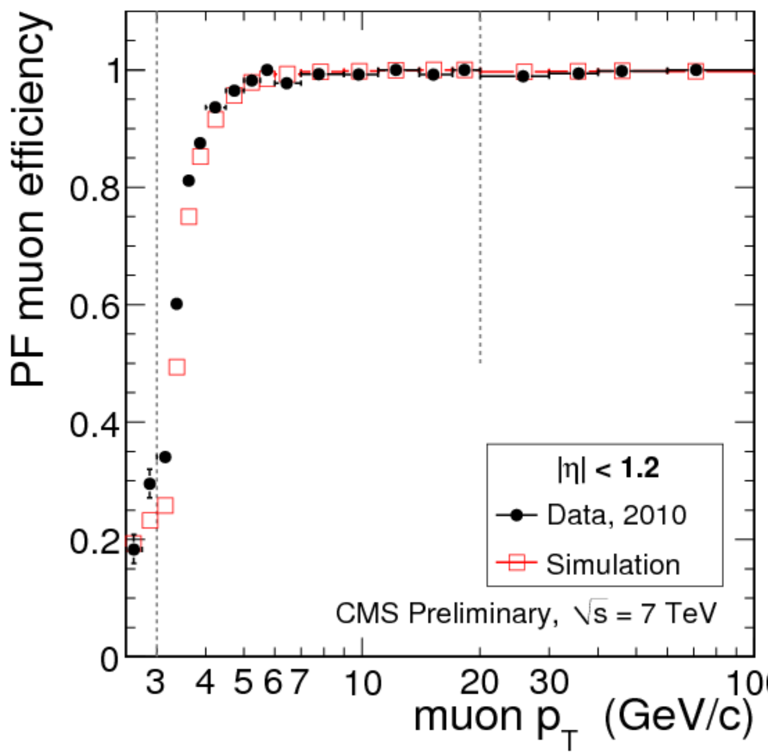
$$A \to \mu^+ \mu^-$$

A = {ω, φ, J/ψ, ψ^*, B_s, ϒ(ns), Z^0}

CMS Muon Performance: Run I

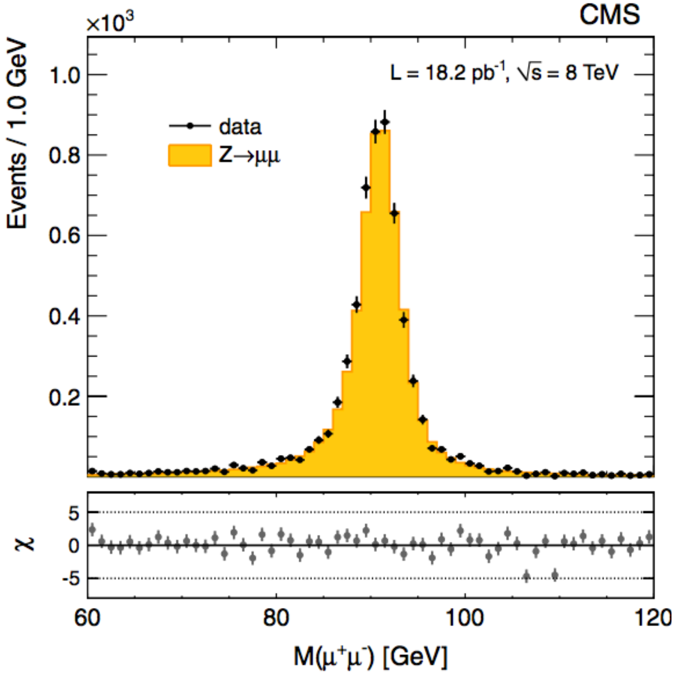
- Exceptionally high muon-reconstruction and identification efficiency has been demonstrated!!





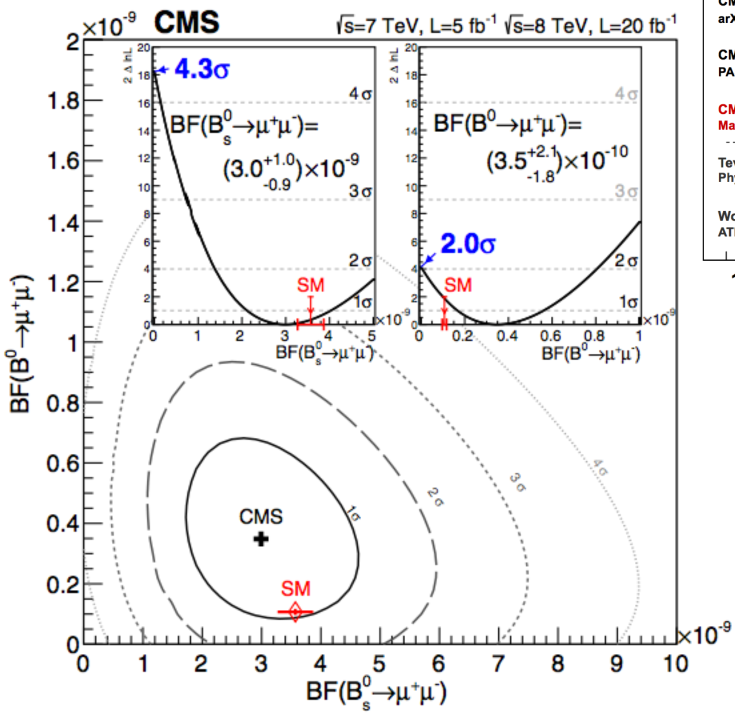
CMS Physics Results: Run I

- Fantastic physics results!!!

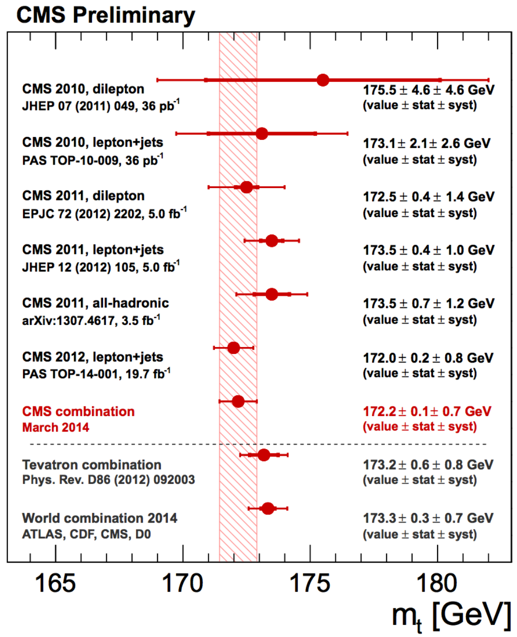


Phys. Rev. Letters, **112**, 191802 (2014)

Phys. Rev. Letters, **111**, 101804 (2013)

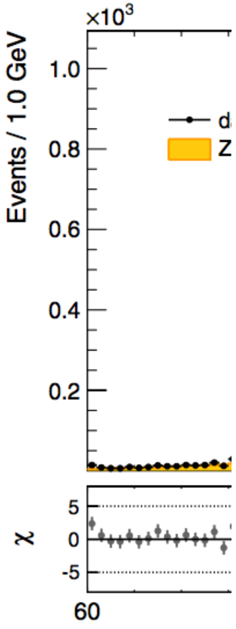


CMS Collaboration, CMS PAS TOP-14-001, 2014.

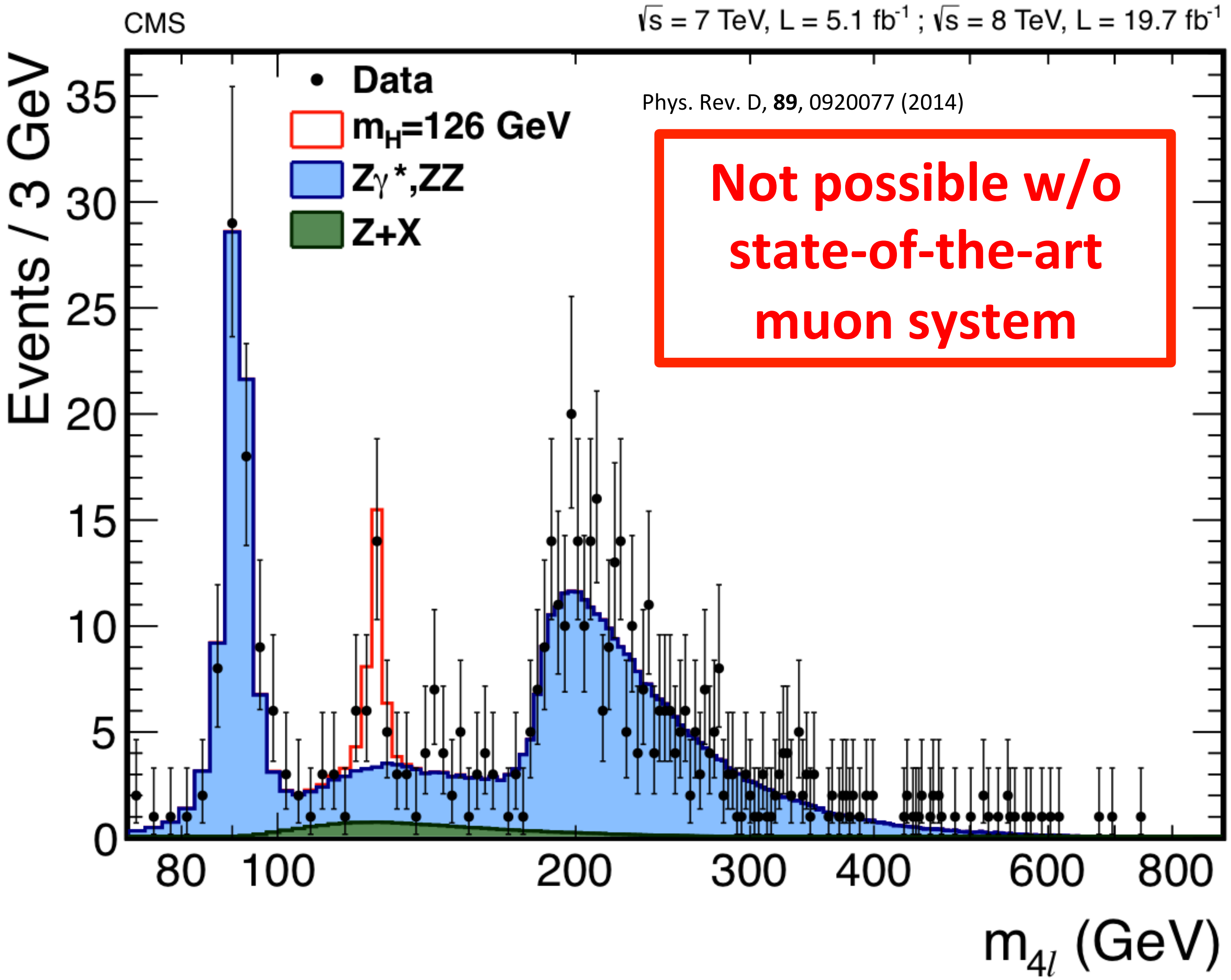


CMS Physics Results: Run I

- Pro



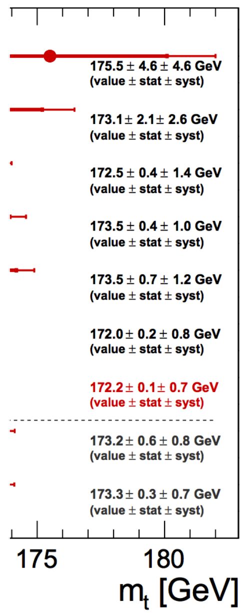
Phys. Rev. Le



Phys. Rev. D, **89**, 0920077 (2014)

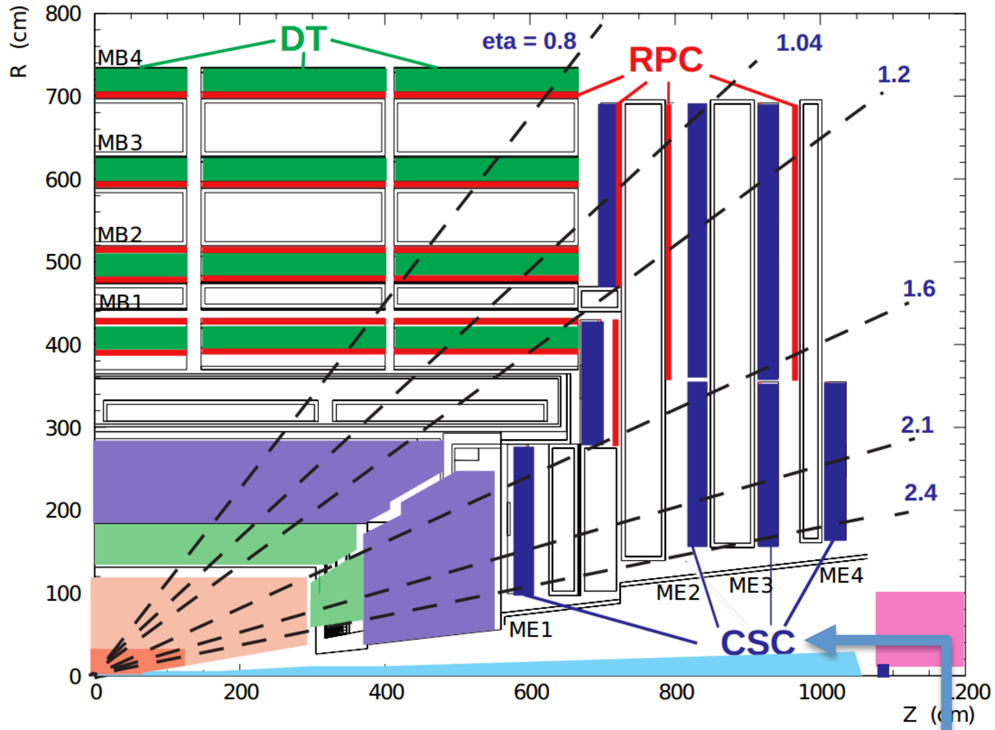
Not possible w/o state-of-the-art muon system

PAS TOP-14-001, 2014.



The Future

- Muon-triggers in CMS from $|\eta|>1.6$ arrive solely from cathode strip chambers (CSC)
- CSC system is at the limit of its performance
- No redundancy!!!
  - Potential problem for physics data taking



Sole System!

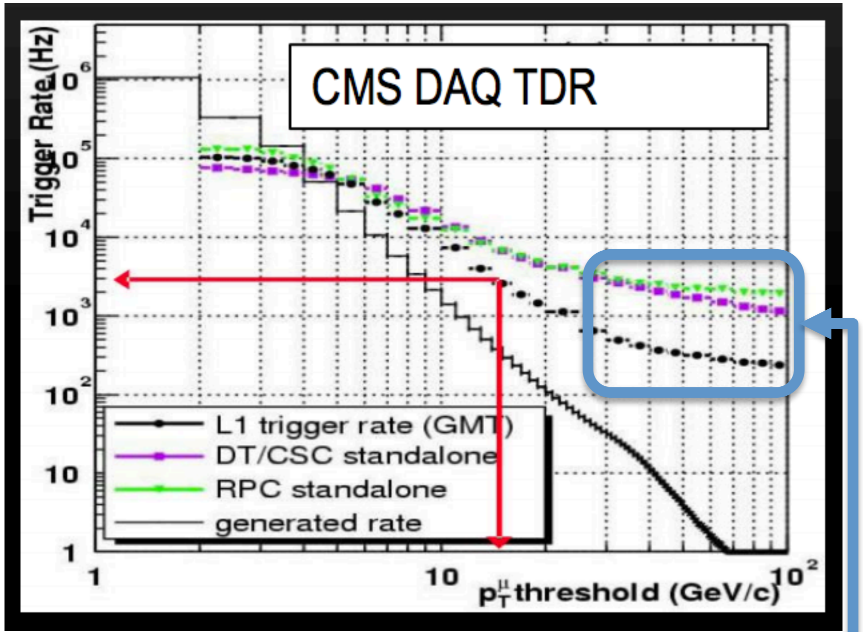
No Redundancy!!!

The Future

- The *rate flattening problem*
  - Low-p_T "soft" muons scatter in the steel return yoke
  - Tracks are incorrectly reconstructed as high-p_T "hard" muons

- Rare occurrence but very high number of soft muons
  - Causes large tail in L1 muon-trigger p_T resolution

- Flattening of L1 trigger rate at high-muon p_T values due to this large tail



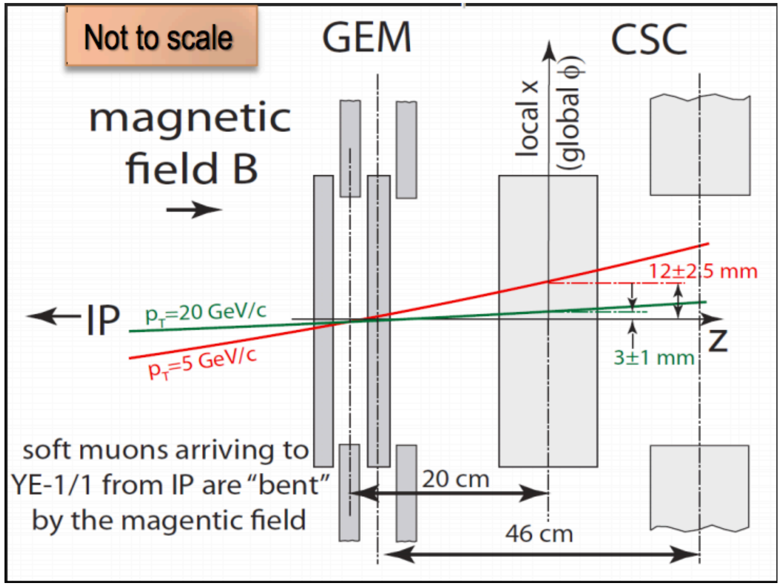
Rate flattening!!!

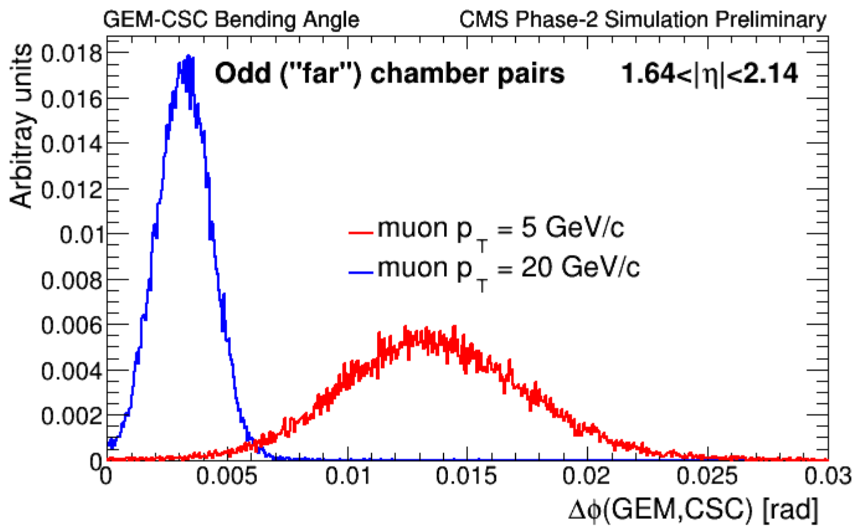
Solution: GEM-CSC Bending Angle

- Additional muon chambers before first CSC station offers significant improvement
- Bending angle:

$$\Delta\phi = \phi_{GEM} - \phi_{CSC}$$

acts as powerful discriminator between soft and hard muons

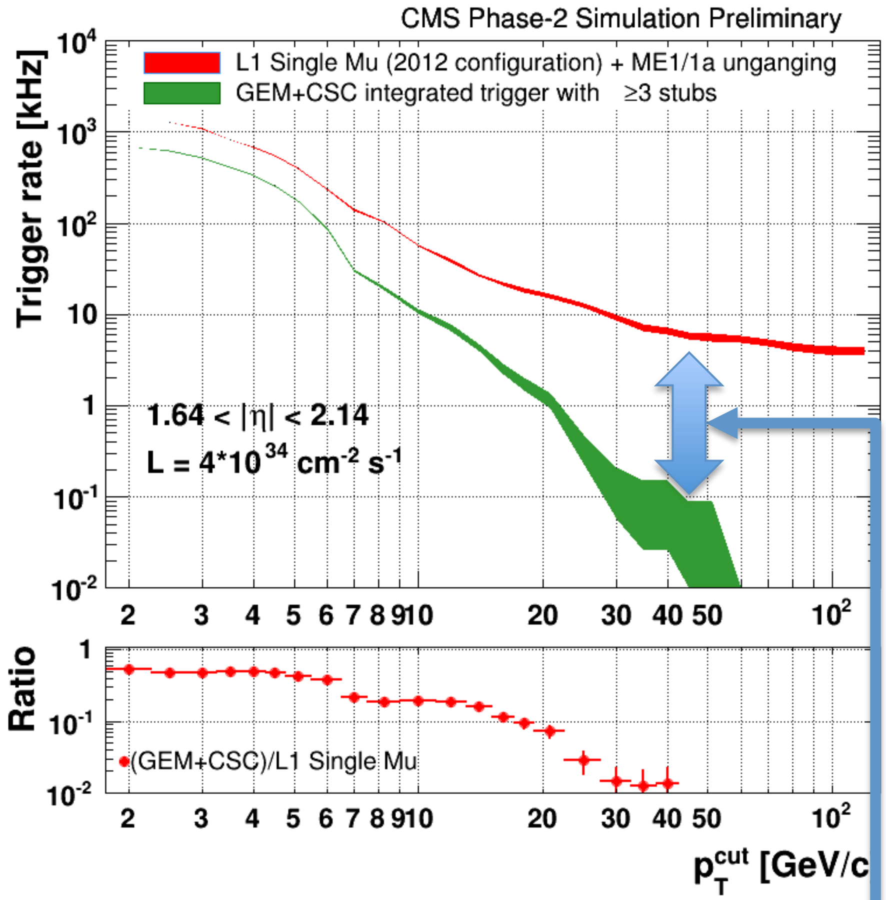




GEMs Solve Rate Flattening

- Studies show triple-GEM detectors are the L1 trigger rate savior of CMS

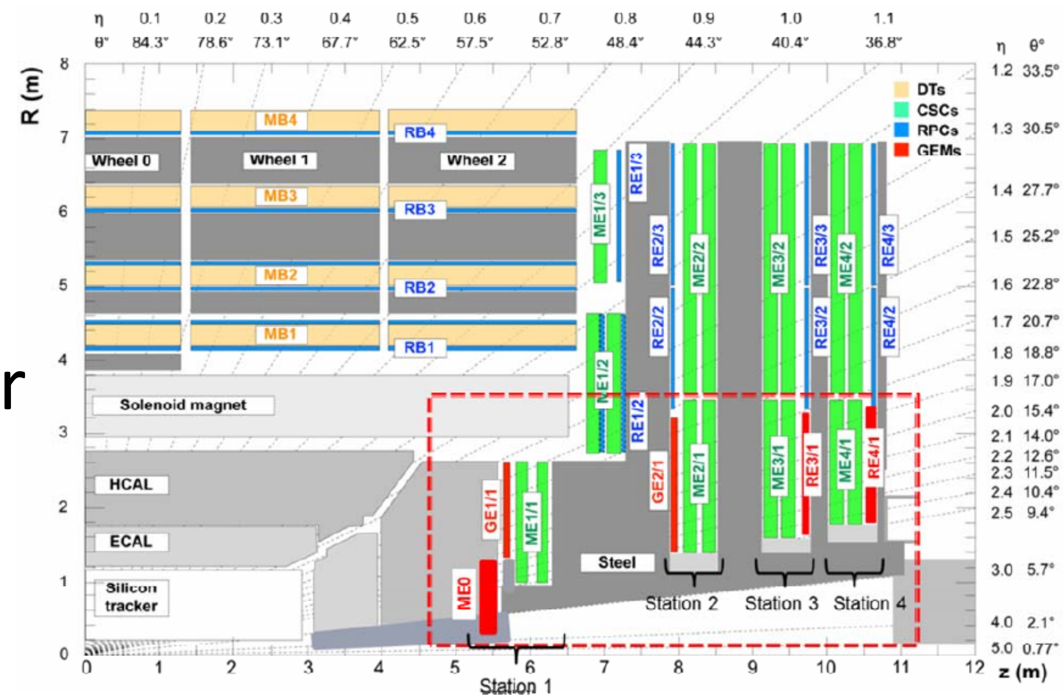
- Additional advantages
  - Low cost
  - High rate capability
  - Radiation hard:
    - Dose > 9mC, no degradation
    - ***See Jeremie's talk!!!!***
  - Good spatial/time resolution:
    - ~100µm; ~4-5ns
  - High Efficiency (~98%)
  - Nonflammable gas mixture
  - Rapid manufacturing time
    - ***See Antonio's talk!!!***



Improvement!!!

The CMS GEM Project

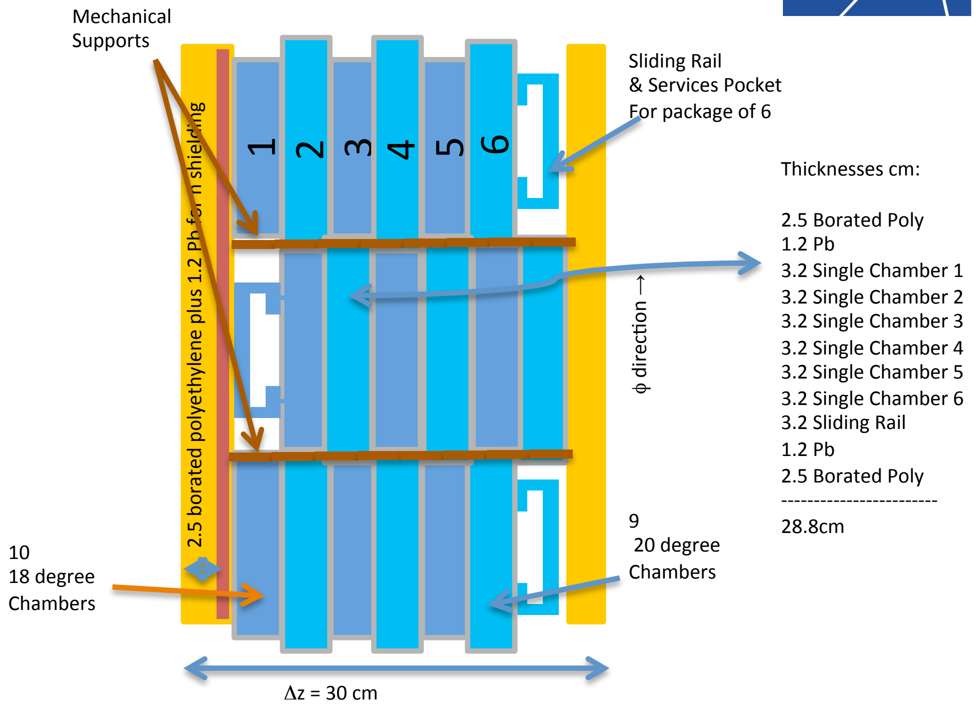
- Create redundancy in muon system
- Robust tracking
- Reduce L1 muon-trigger and HLT rates by improving muon p_T resolution
- Ensure ~100% trigger efficiency in post LS2 *pp* collision environment
  - *High pile up!*
    - LS2 (LS3) <PU> = 70(140)

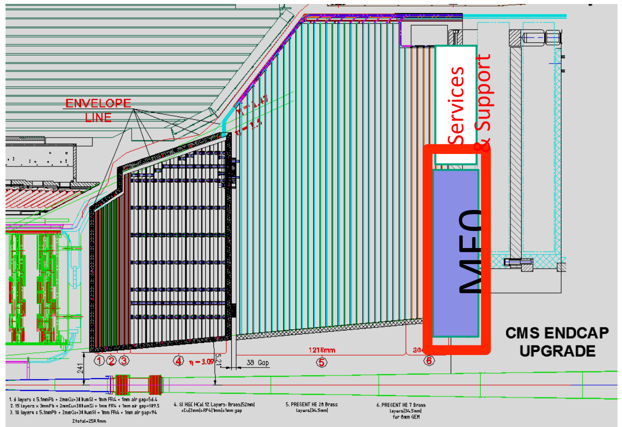


Proposal to install triple-GEM detectors in the forward region of CMS

ME0 System

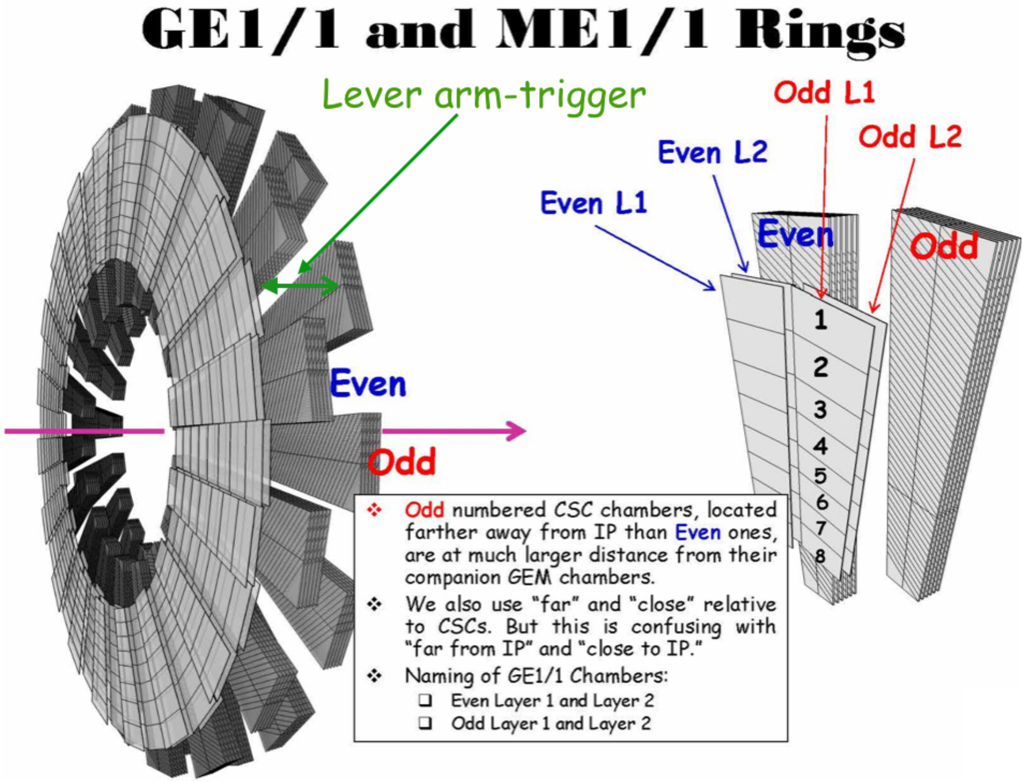
- $2.0 < |\eta| < 3.5$
  - 20° wedges affixed to back of upgraded CMS HCAL endcap
- Six layers of triple-GEM detectors
  - Design ongoing
- **Significantly increases muon acceptance for high profile analyses**
  - e.g. H->ZZ->4μ
- Total foil area ~144m^2





Current Focus: GE1/1 System

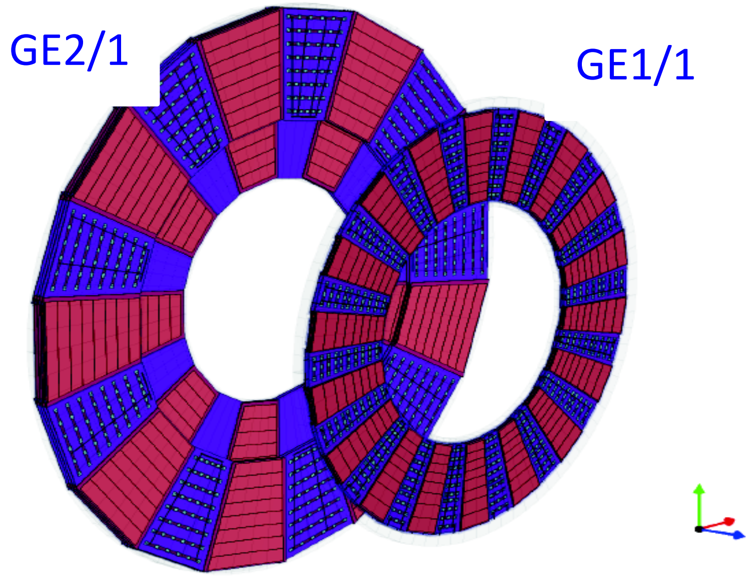
- 1.55 < |η| < 2.18
  - Short and long chambers for maximum coverage
- 36 superchambers (SC) per side of CMS
  - Each chamber spans 10° in φ
  - 2 chambers/SC
  - 144 chambers total
- Total foil area ~140m^2



Four years of R&D has given us five prototype generations; each an improvement of the last!!!

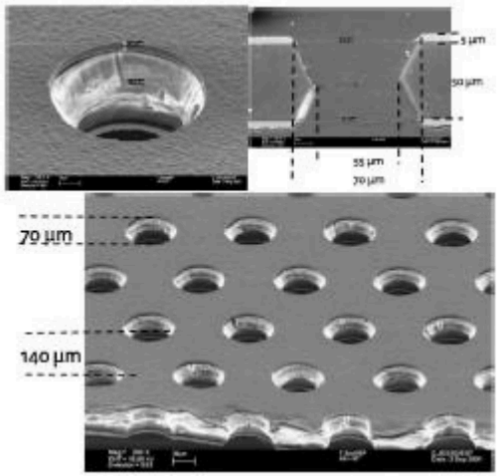
GE2/1 System

- $1.55 < |\eta| < 2.45$
- Each chamber spans 20°

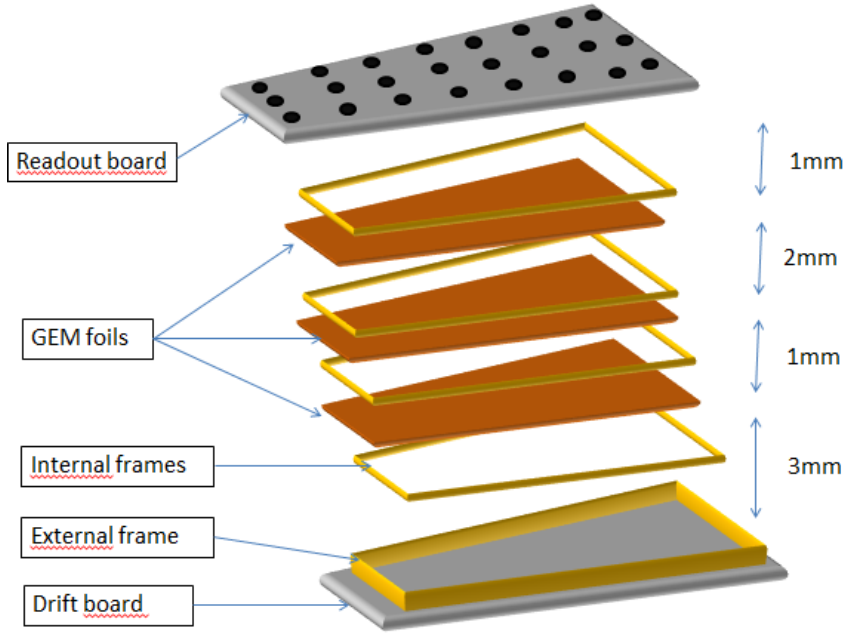


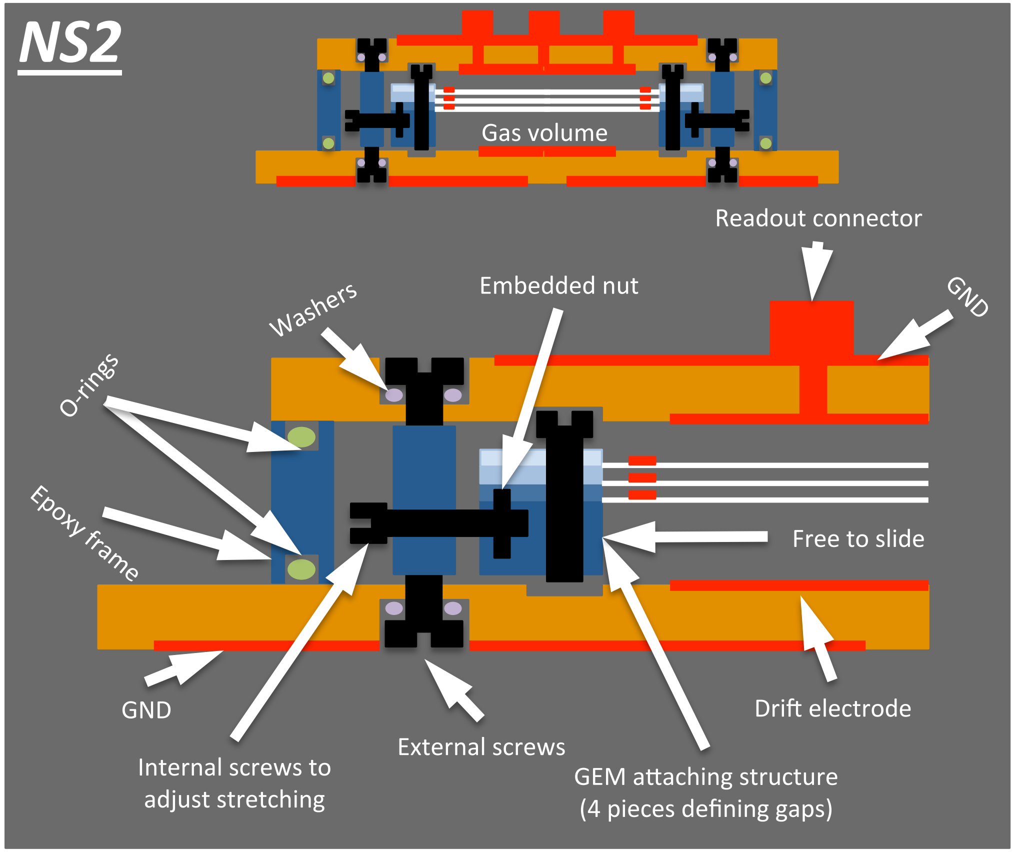
- Design on-going
- Targeting two rings of double-layered triple-GEM detectors
- Total foil area ~145m^2

Current Prototype: GE1/1-V5

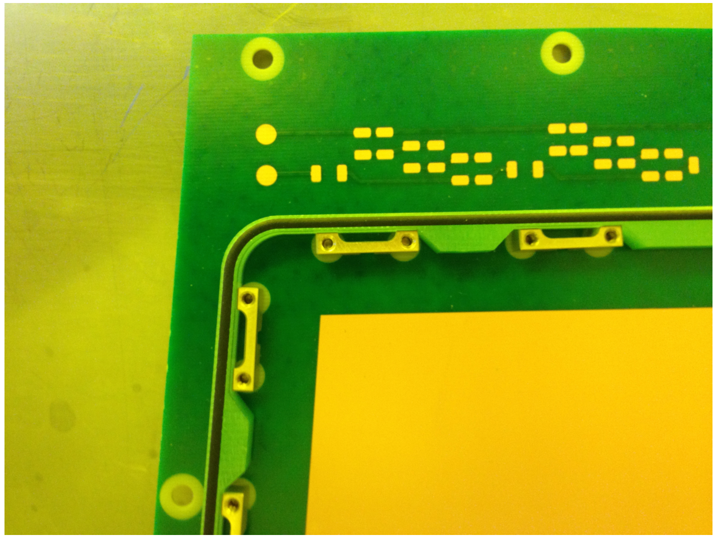


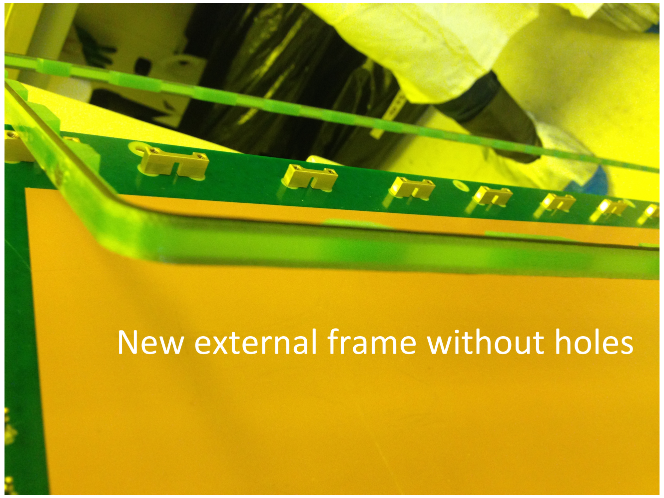
- Triple-GEM foils 5:50:5µm for Cu:Kapton:Cu
  - 70µm diam.; 140µm pitch
- Gap configuration (in mm): 3/1/2/1
- NS2 assembly technology; no spacers or glue!

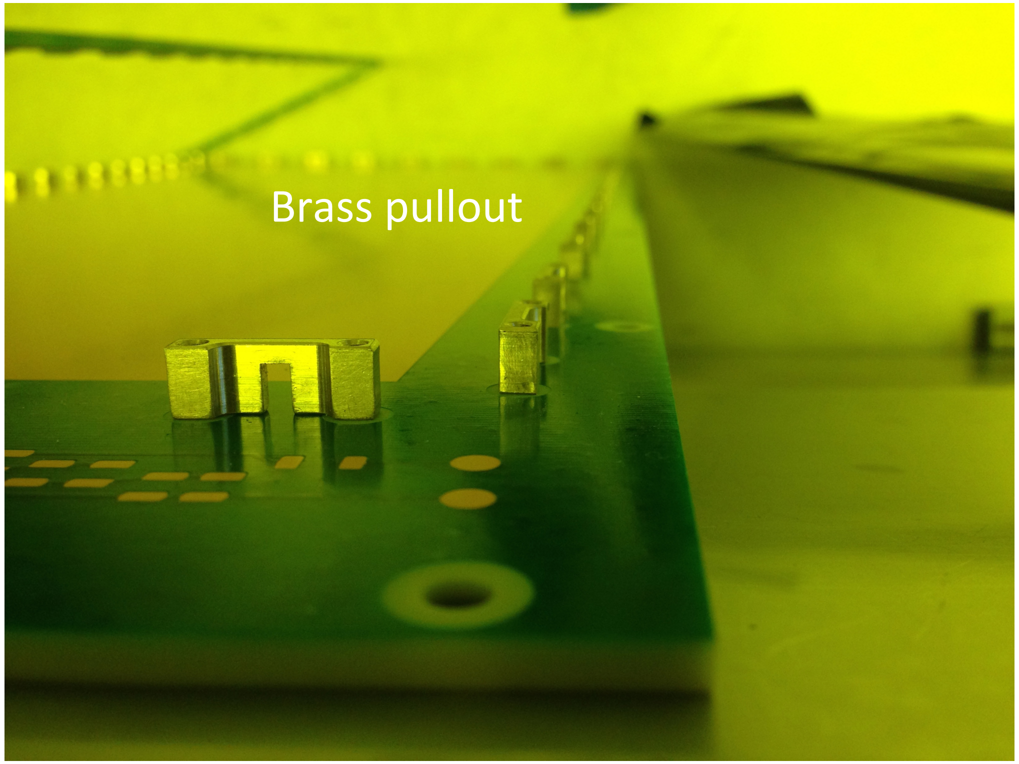




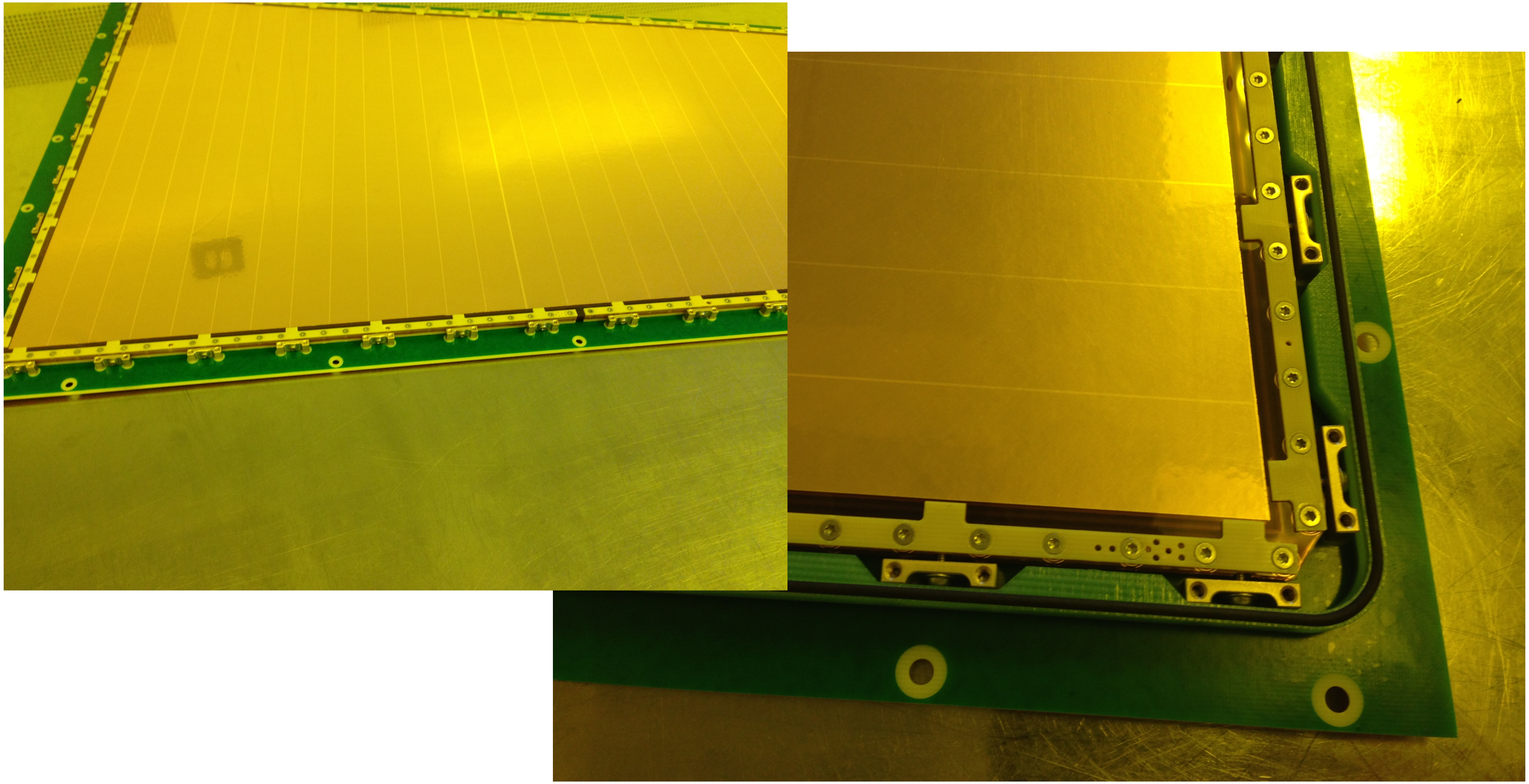
Assembly of GE1/1-V5 Prototype



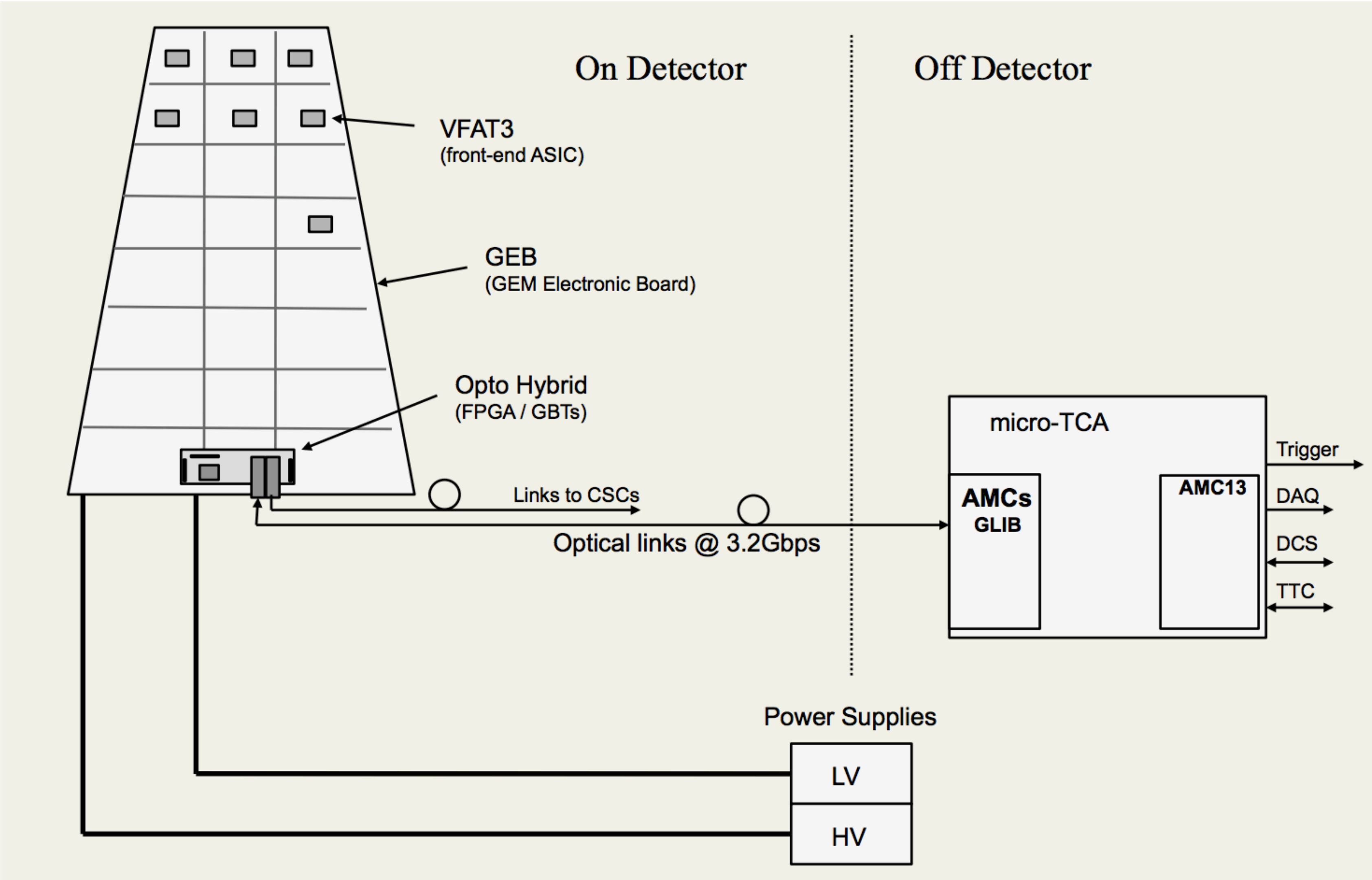




Assembly of GE1/1-V5 Prototype

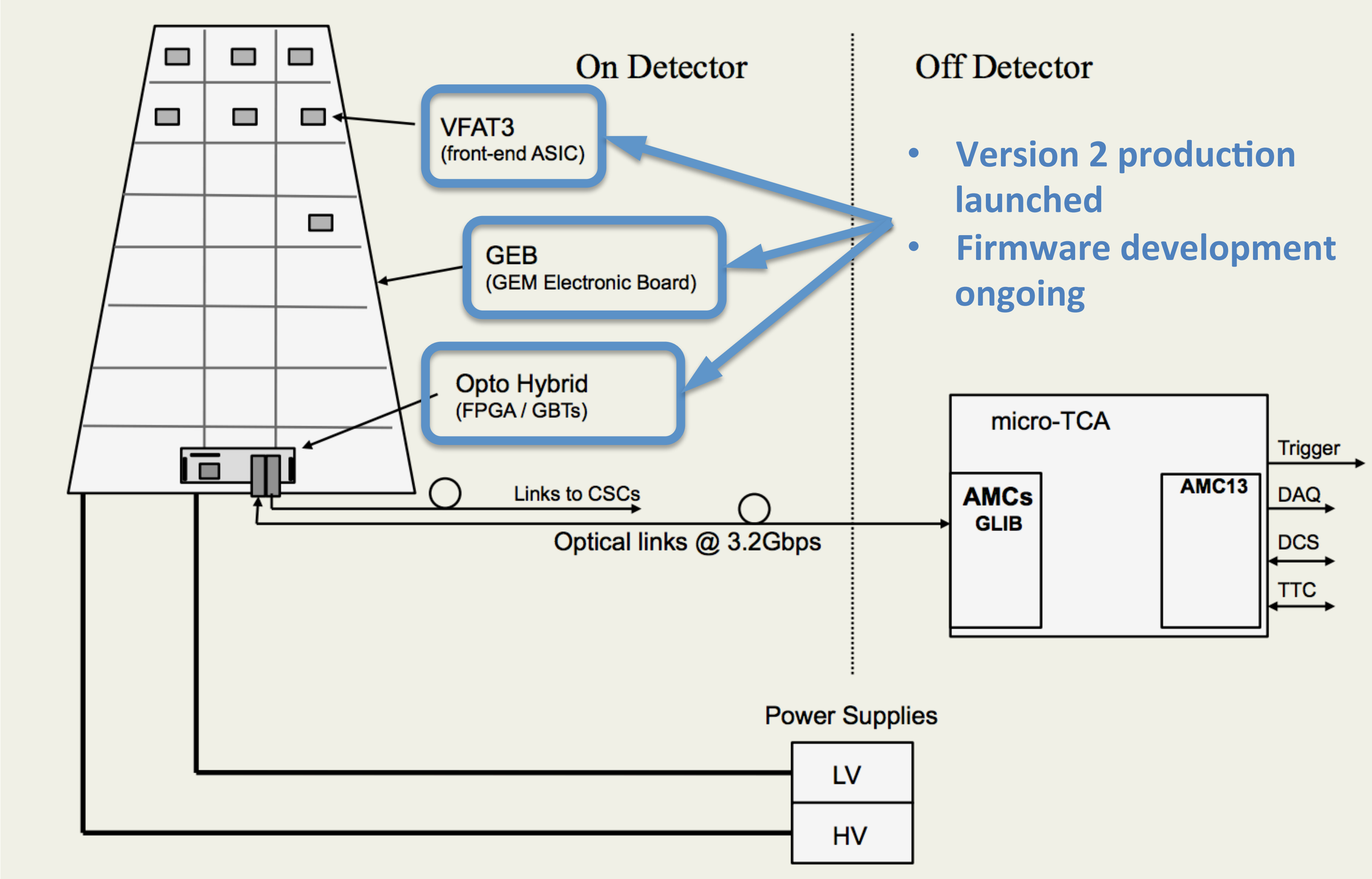


GEM DAQ



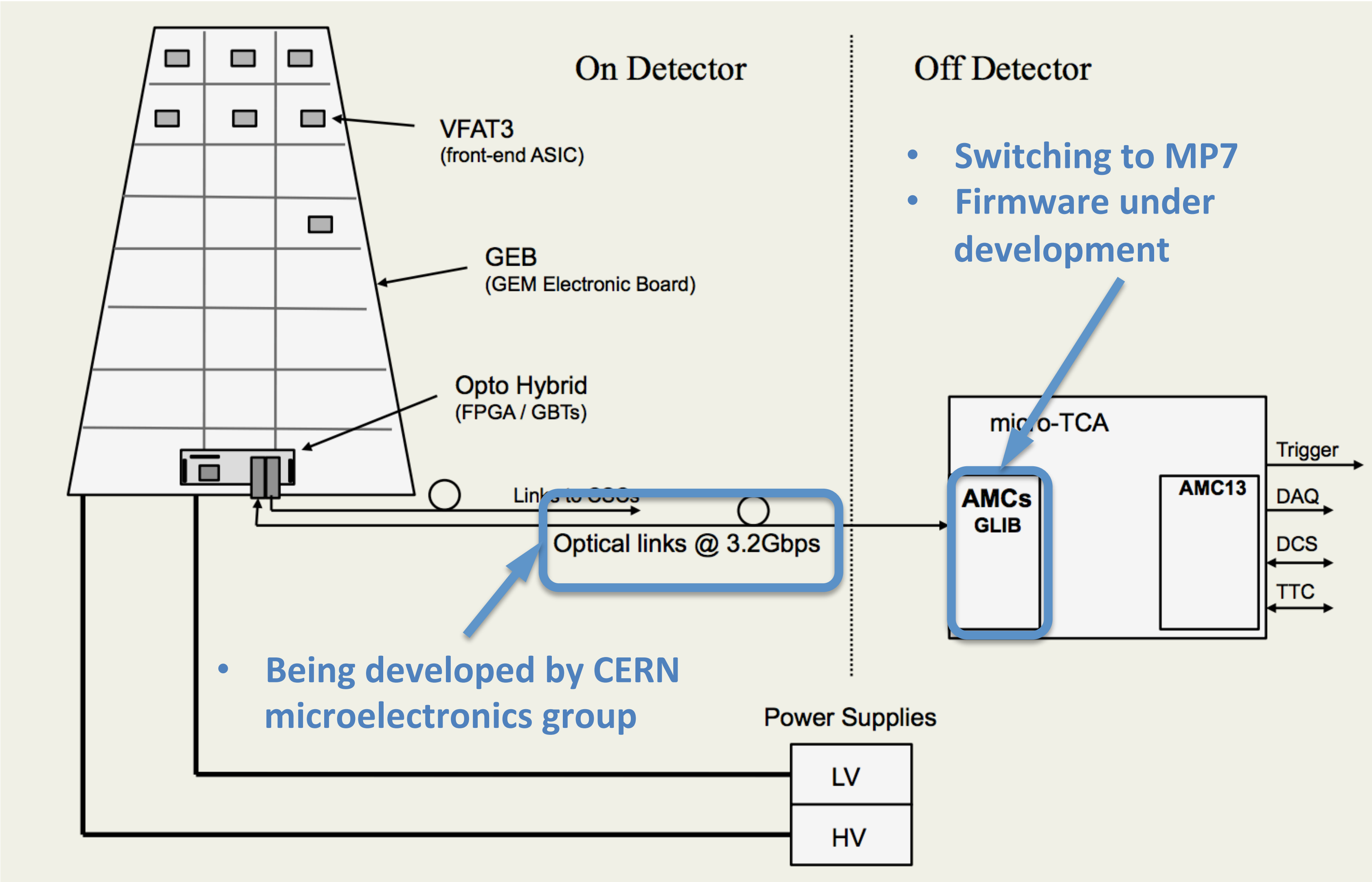
On Detector
Off Detector
VFAT3
(front-end ASIC)
GEB
(GEM Electronic Board)
Opto Hybrid
(FPGA / GBTs)
Links to CSCs
Optical links @ 3.2Gbps
micro-TCA
AMCs
GLIB
AMC13
Trigger
DAQ
DCS
TTC
Power Supplies
LV
HV

GEM DAQ – Status

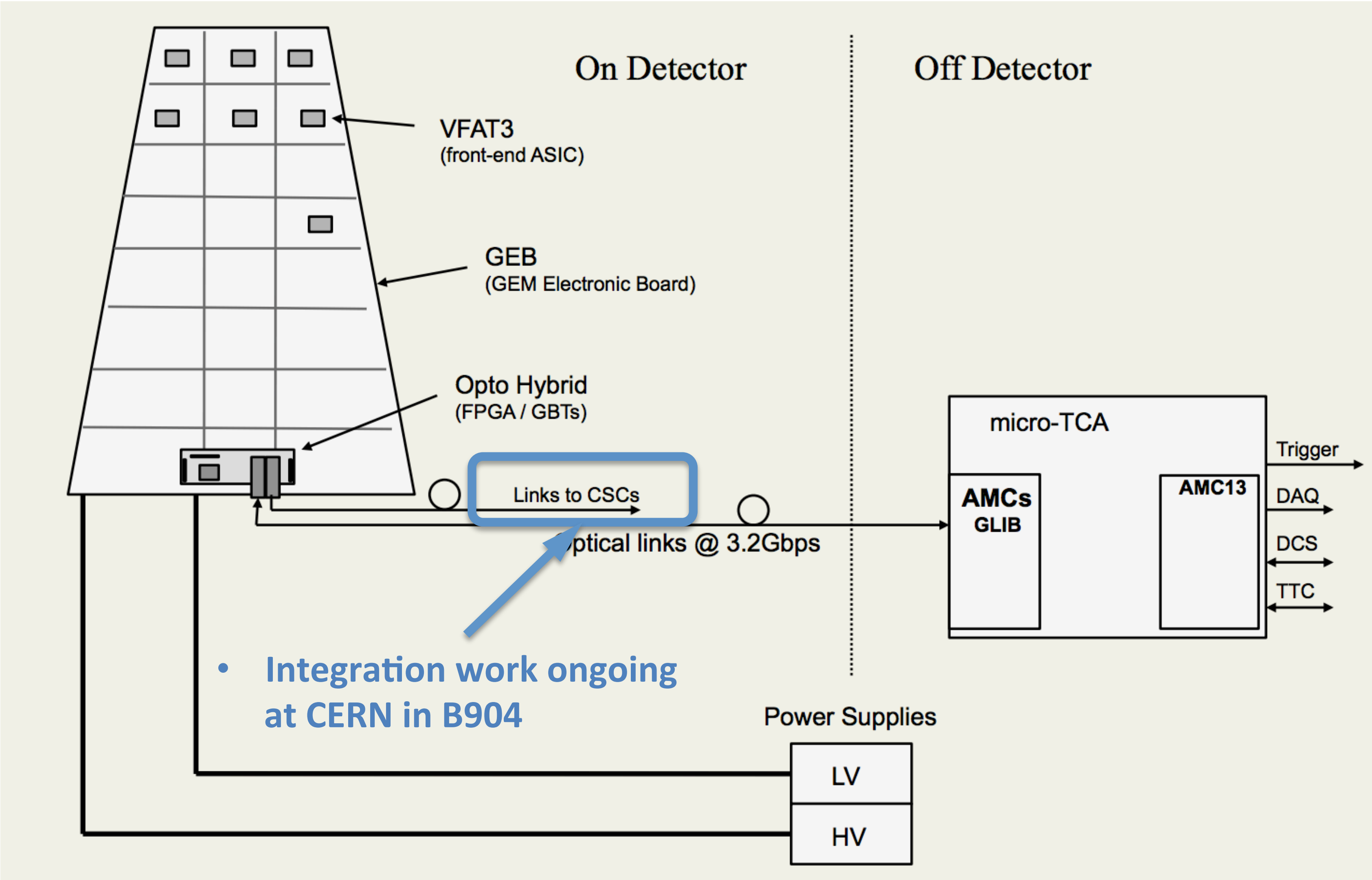


- Version 2 production launched
- Firmware development ongoing

GEM DAQ – Status



GEM DAQ – Status



- Integration work ongoing at CERN in B904

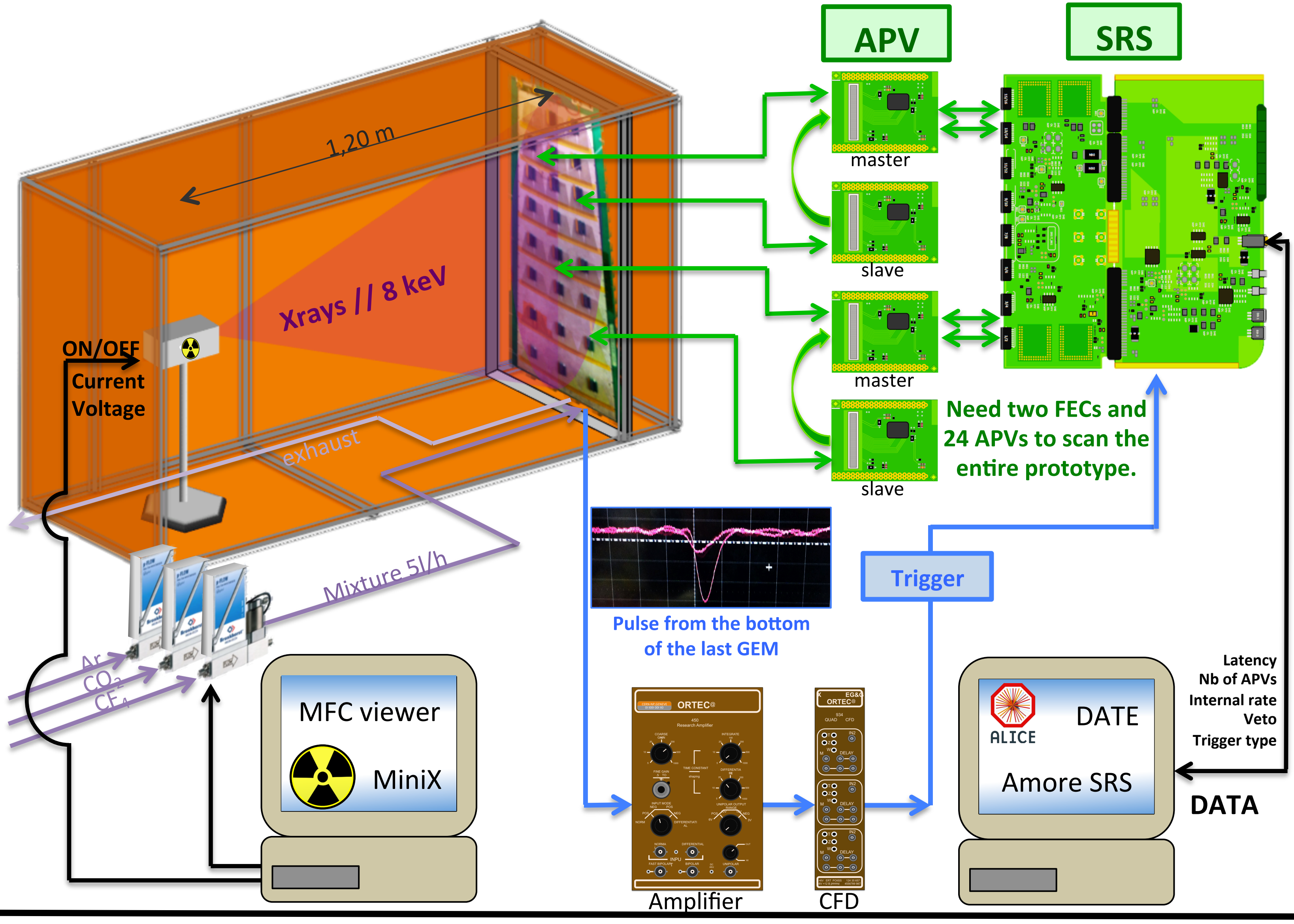
On-going Activities

- Prototype production
- X-ray station
- CMS GEM Training School
- Cosmic stand
- CSC-GEM integration stand
- Fall 2014 Test Beam
- GE1/1 Slice Test in 2016

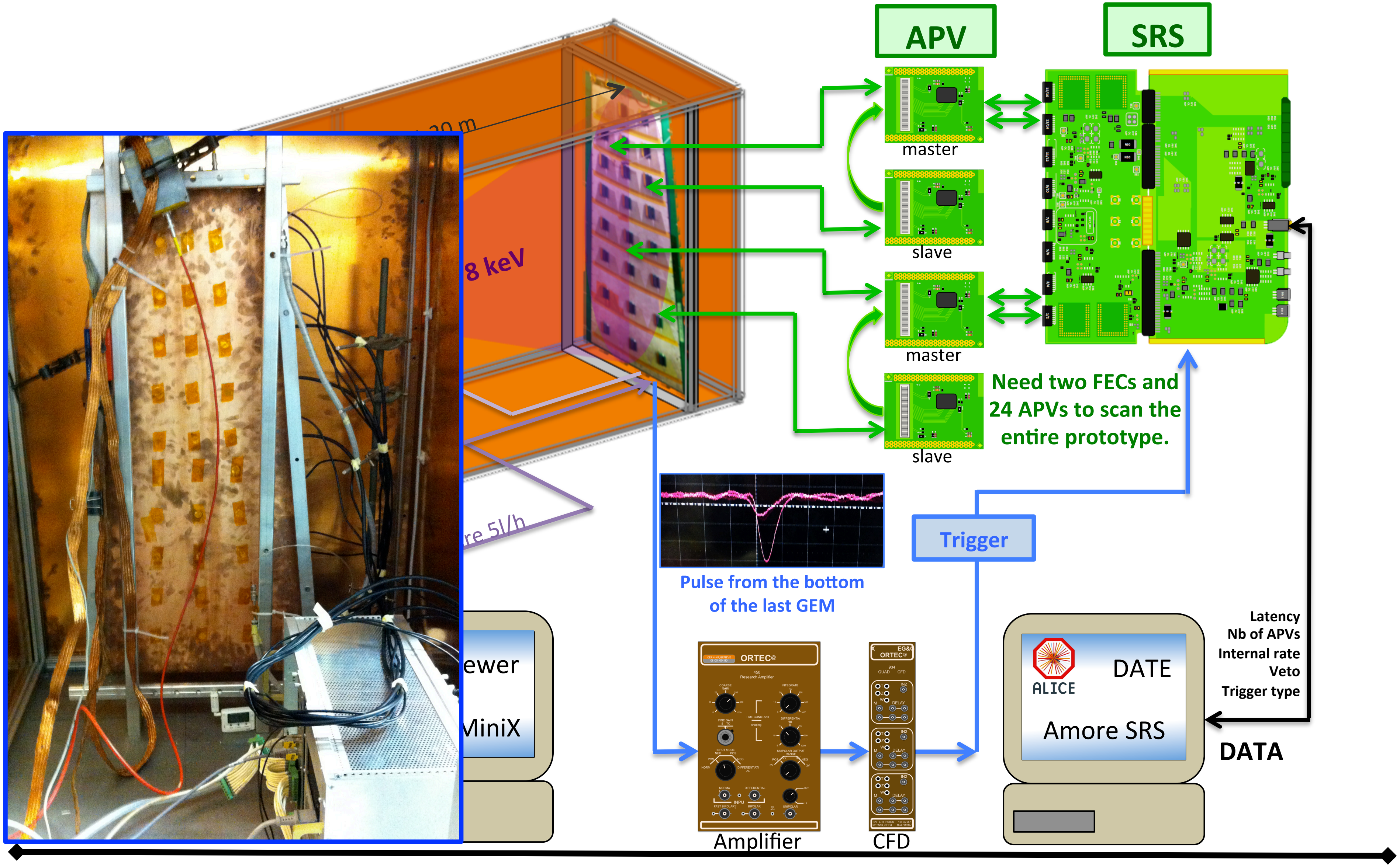
Prototype Production

See Sinem's talk regarding status of production sites!!!

X-Ray Station: Gain Uniformity

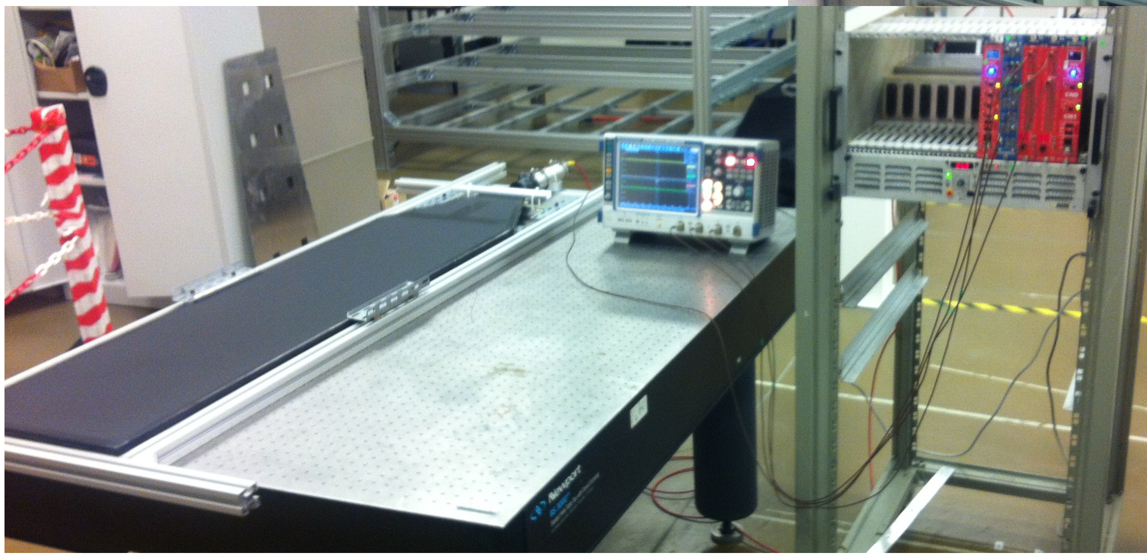


X-Ray Station: Gain Uniformity



TIF Cosmic Stand

- Additional layer of quality control
- Construction on going
- Aluminum superstructure completed
- Assembling scintillators and trigger logic presently



CMS GEM Training School

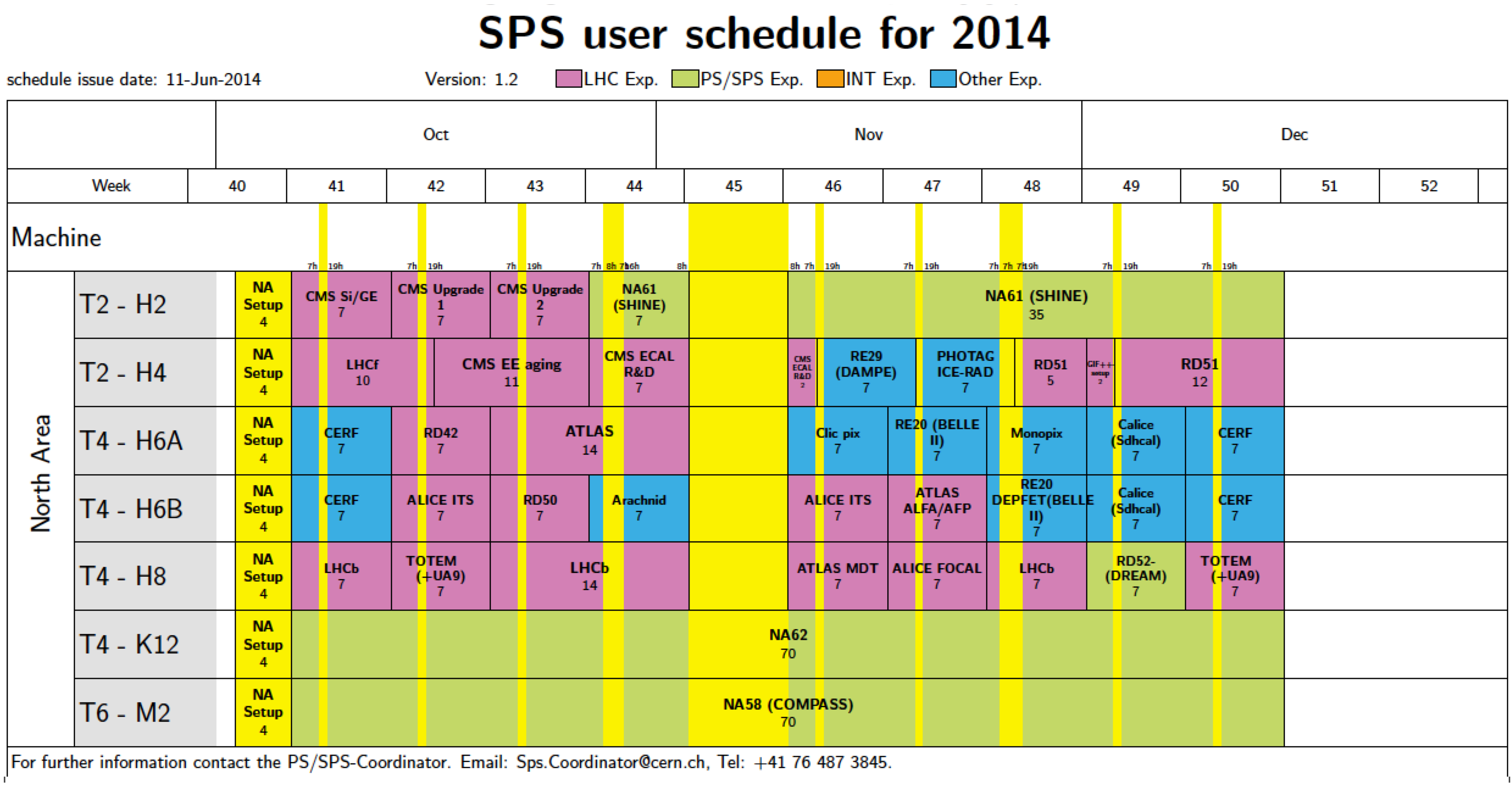
- Introduce new members of the collaboration to principals of triple-GEM detectors
  - Leakage current
  - Assembly
  - HV stability
  - Gain calibration

- Train expert collaborators in the use of SRS+APV system for gain calibration measurements
  - Critical to large scale production of GE1/1 system

CSC-GEM Integration Stand

- Goal: Slice test readiness
  - CSC track finding algorithm commissioned before slice test
- Full ME1/1 CSC chamber present in B904
- Plan to add GE1/1 prototype in tandem
  - Position as if they were in CMS
- Use cosmics to develop cross chamber communication and trigger logic

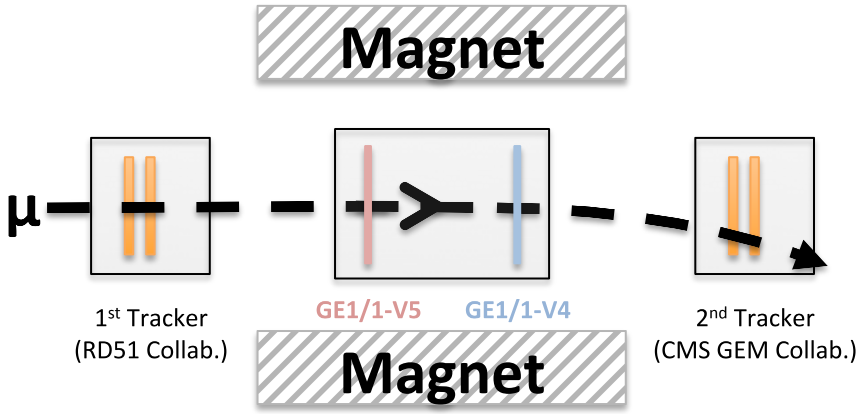
Fall 2014 Test Beam



Fall 2014 Test Beam Setup

H2 Test Beam w/Magnet

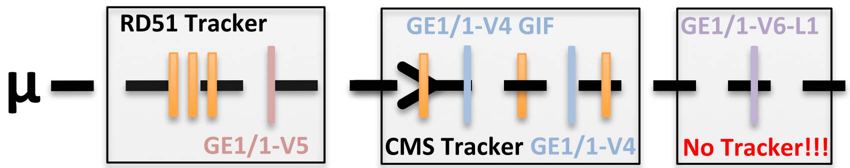
- October 13th – Nov 2nd



- Charge sensitive performance measurements in high **B** field
- Test version one of GEM electronics

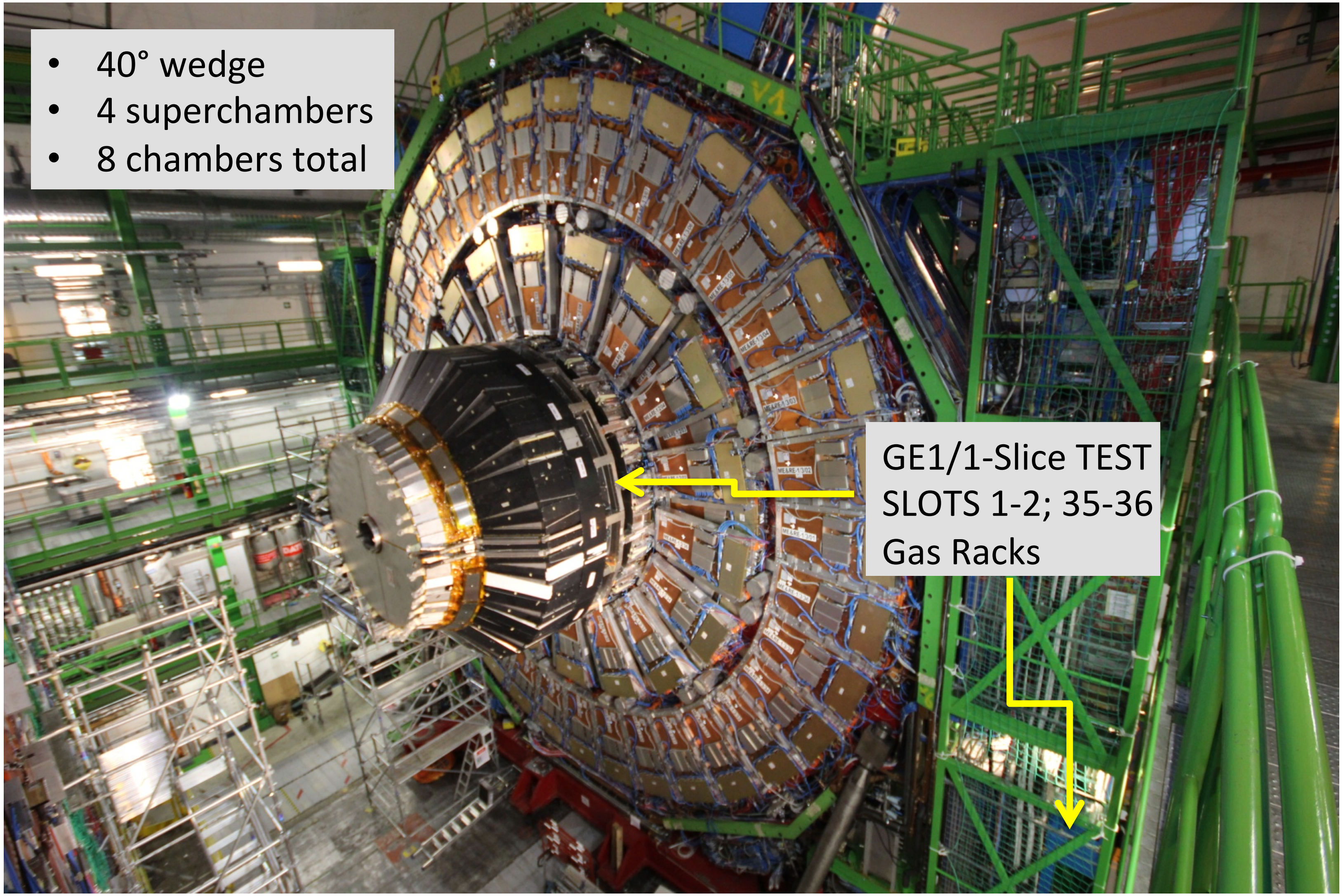
H4 Test Beam w/Magnet

- Nov 26th – Dec 15th



- Timing sensitive performance measurements with **B**=0
- Study impact of radiation dose on performance
- Test of version two of GEM electronics

GE1/1 Slice Test



On-going Activities

- X-ray station
- CMS GEM Training School
- Cosmic stand
- CSC-GEM integration stand
- Fall 2014 Test Beam
- GE1/1 Slice Test in 2016

- ***You can get involved! Ask how!!!***
  - ***Discoveries around the corner!!!***

Conclusion

- Post LS2 presents a challenging *pp* collision environment
- To maintain ability to perform competitive physics measurements CMS must adapt
- Muon upgrade based on triple-GEM detectors is an ideal solution for post LS2 operations

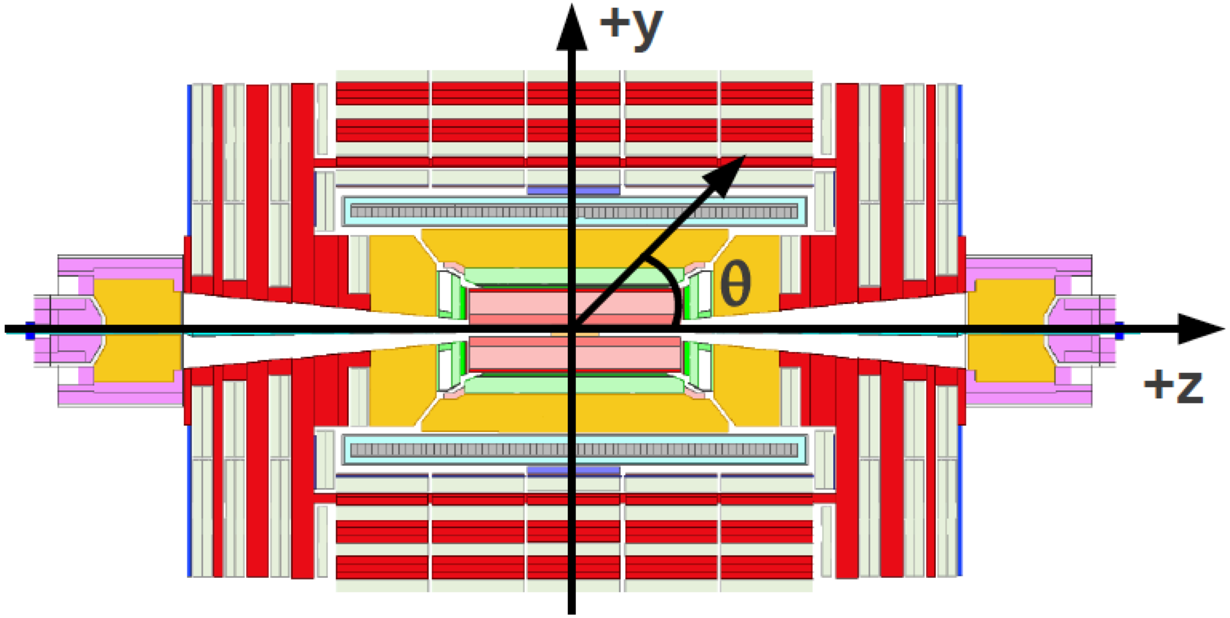
BACK-UP SLIDES

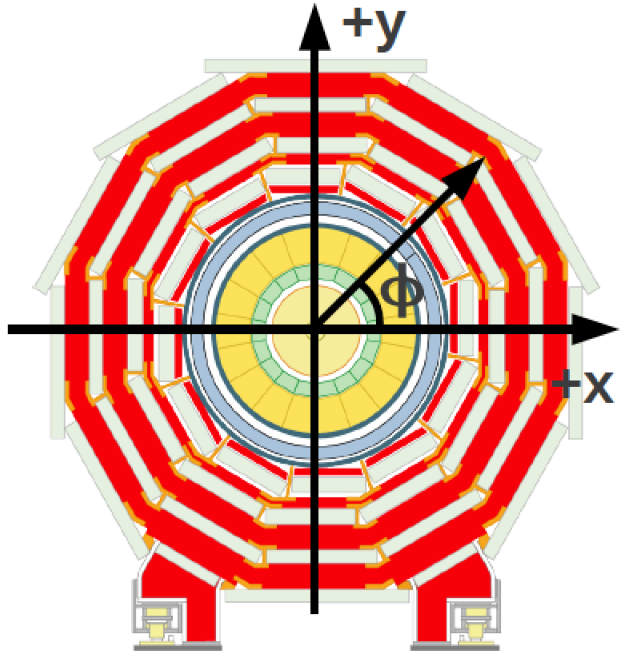
Muon Reconstruction in CMS

- Tracks independently reconstructed in:
  - Silicon tracker, referred to as *tracker tracks*
  - Muon chambers, referred to as *standalone-muon tracks*

- Global muon reconstruction via outside-in approach
  - Attempts to match a standalone-muon track to a tracker track
- Tracker muon reconstruction via inside-out approach
  - Tracker tracks extrapolated to muon chambers
  - Attempt to match to track stub in muon chambers

CMS Coordinate System





$$\eta = -\ln\left(\tan(\theta/2)\right) \qquad \Delta\phi = \phi_2 - \phi_1 \qquad \Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$$

$$p_T = \sqrt{p_x^2 + p_y^2} \qquad \Delta\eta = \eta_2 - \eta_1 \qquad \Delta A = \Delta\phi \text{ or } \Delta R$$

CMS Collaboration, Detector Drawings, CMS-PHO-GEN-2012-002.