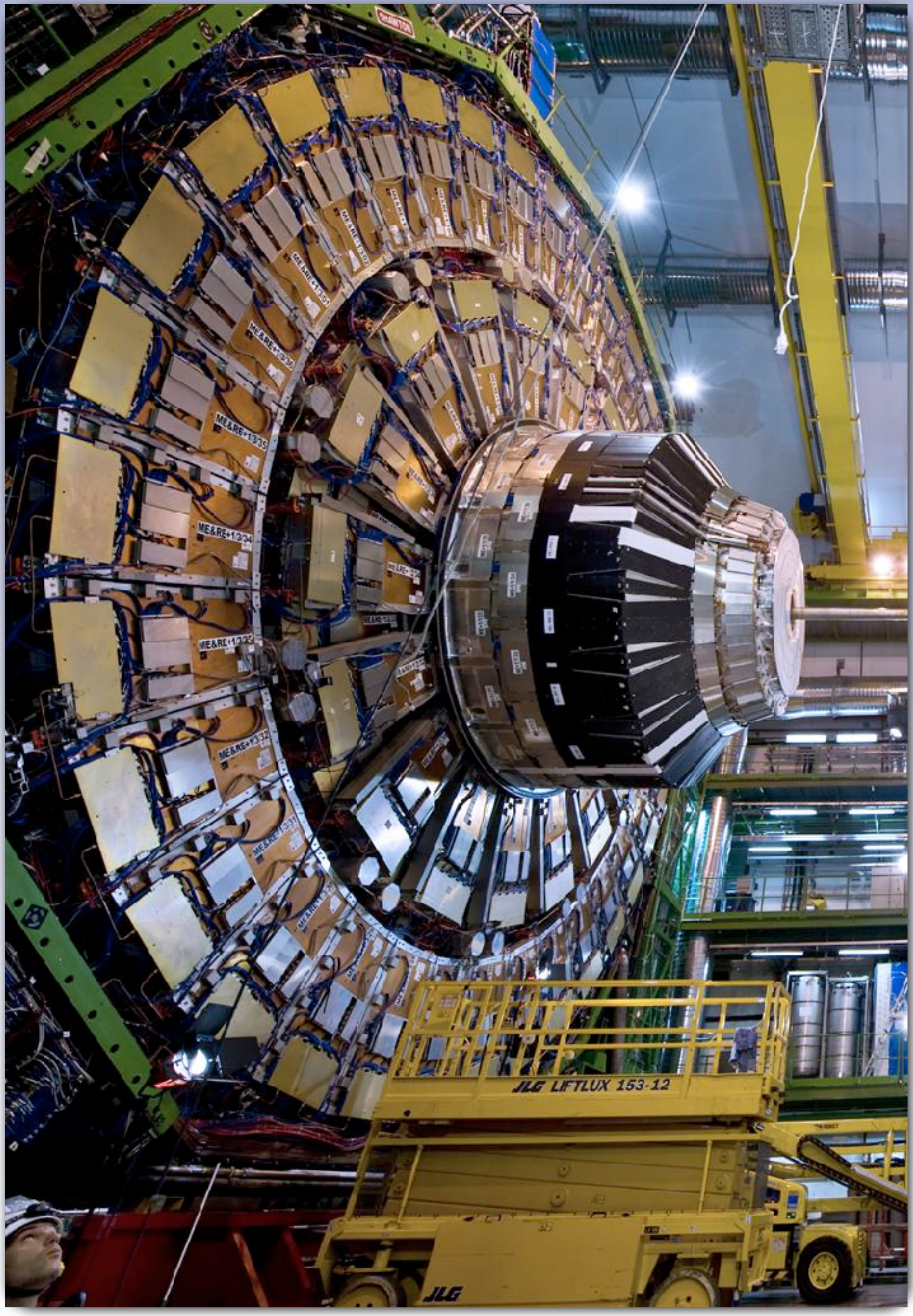


Lecture #1: Introduction to the CMS CSC system

Manuel Franco Sevilla
UC Santa Barbara

<u>16th July 2018</u>

Intro to CSC electronics + DOC training

Outline

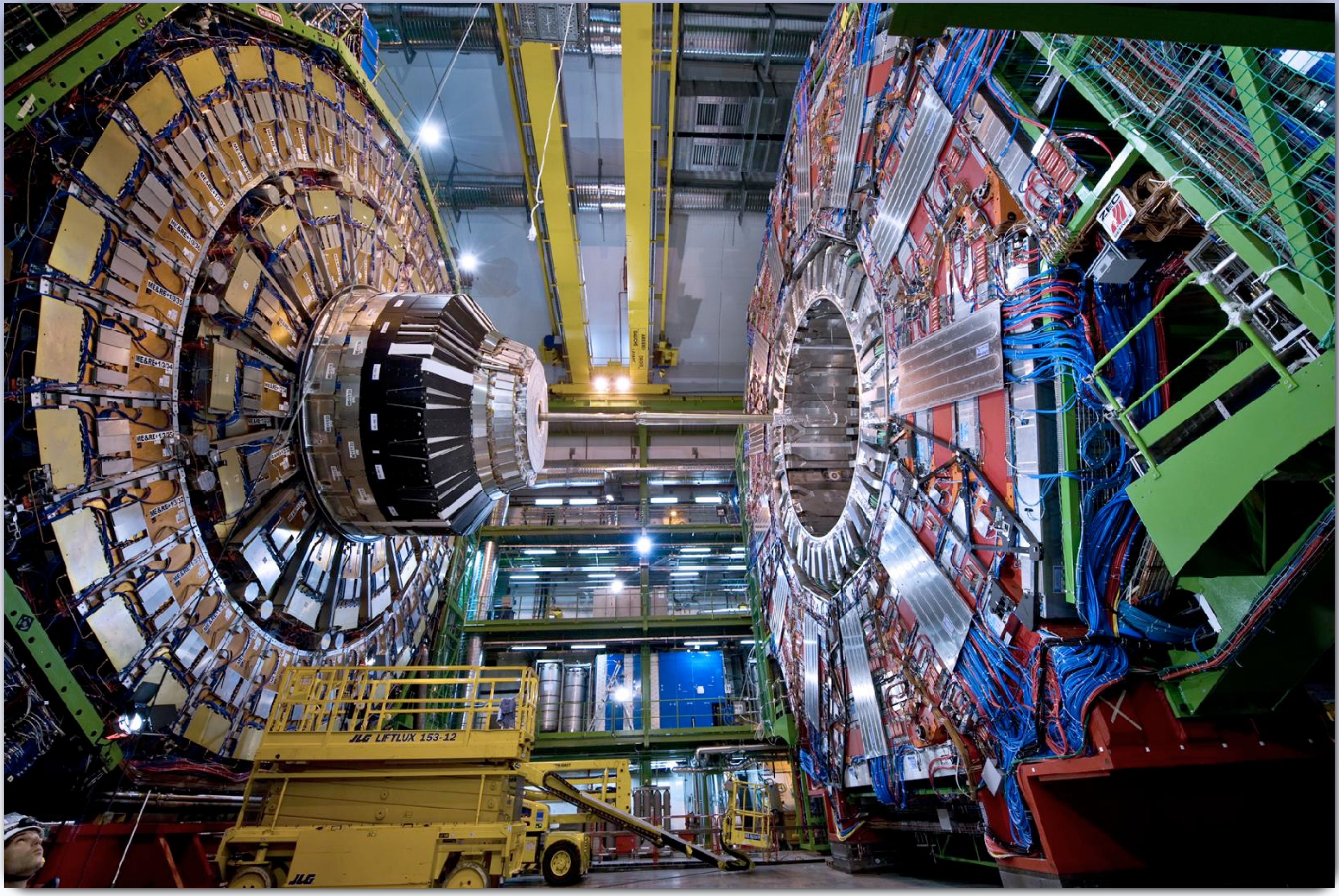
Lecture #1: Introduction to the CSC system

1. The CMS muon system
2. Chamber nomenclature
3. The Cathode Strip Chambers
   - Chamber, gas, HV, electronics, LV
4. CSC group structure

Lecture #2: Introduction to the CSC electronics

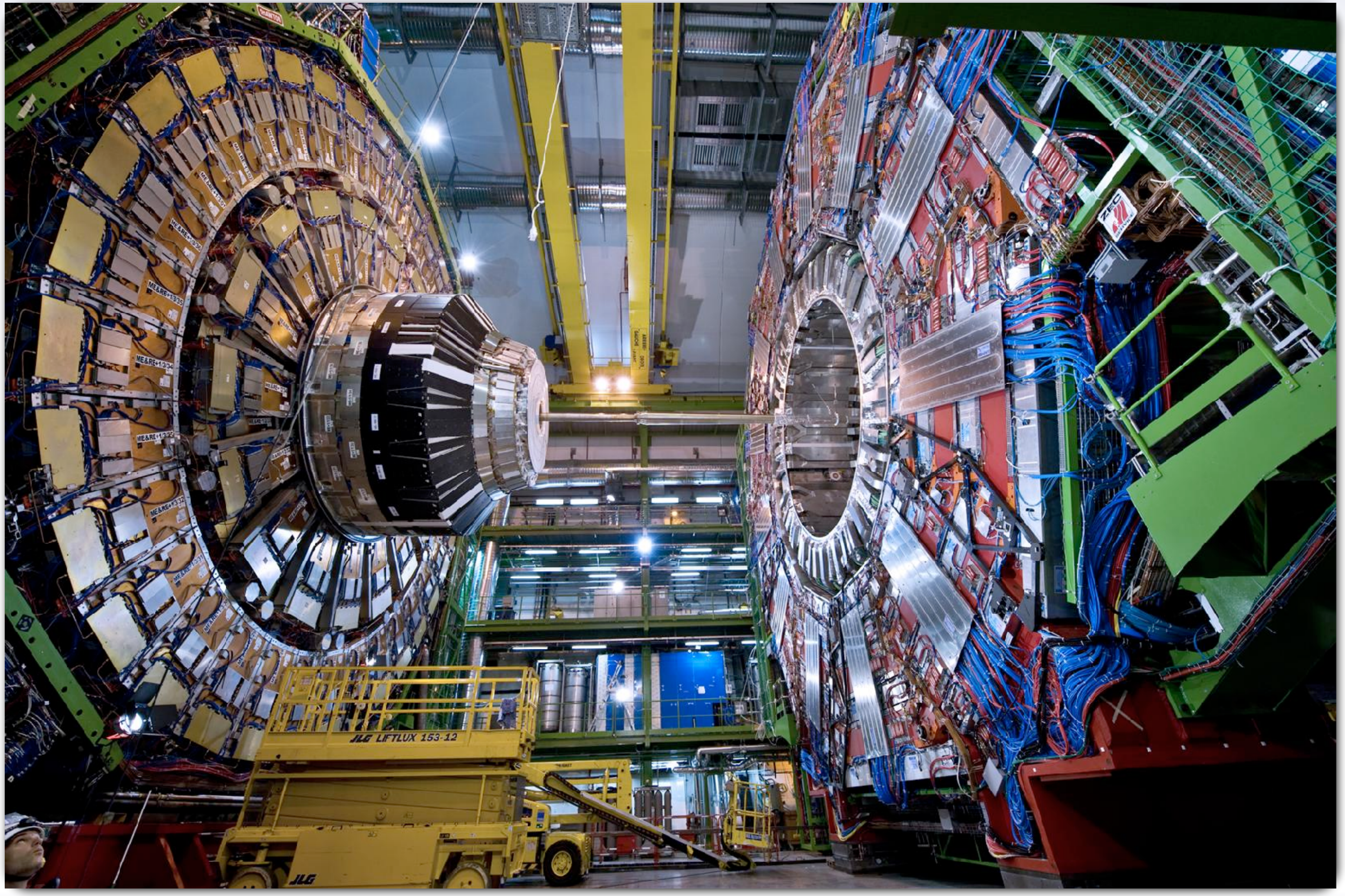
1. Original CSC electronics
2. Phase-1 upgrade (LS1)
3. Phase-2 upgrade (LS2-LS3)

Run 1			**LS1**		Run 2				**LS2**		Run 3			**LS3**		Run 4			
2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029



The CMS Muon System

The Compact **Muon** Solenoid

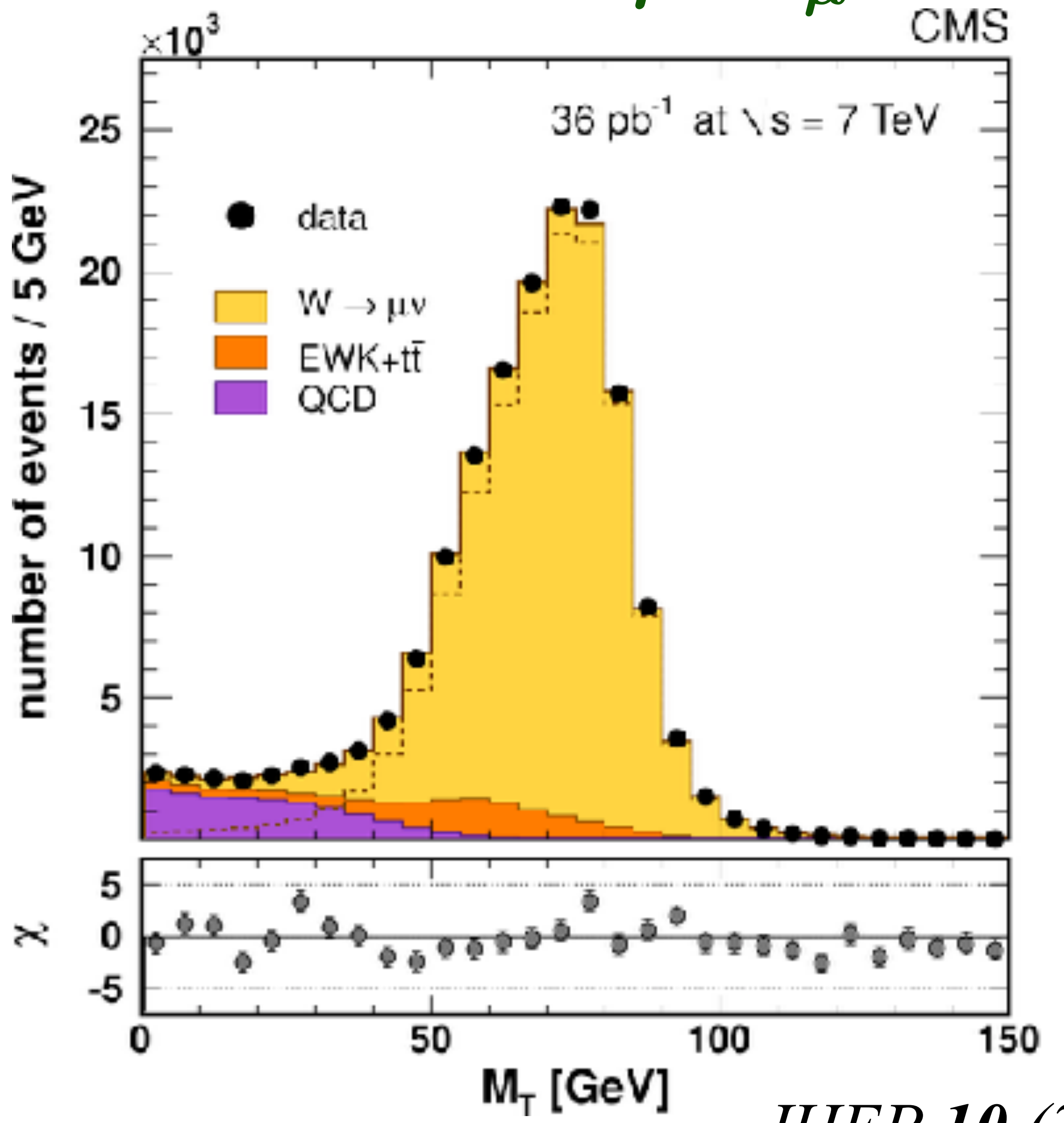


- In the 1994 technical proposal for CMS, the **design goals** were

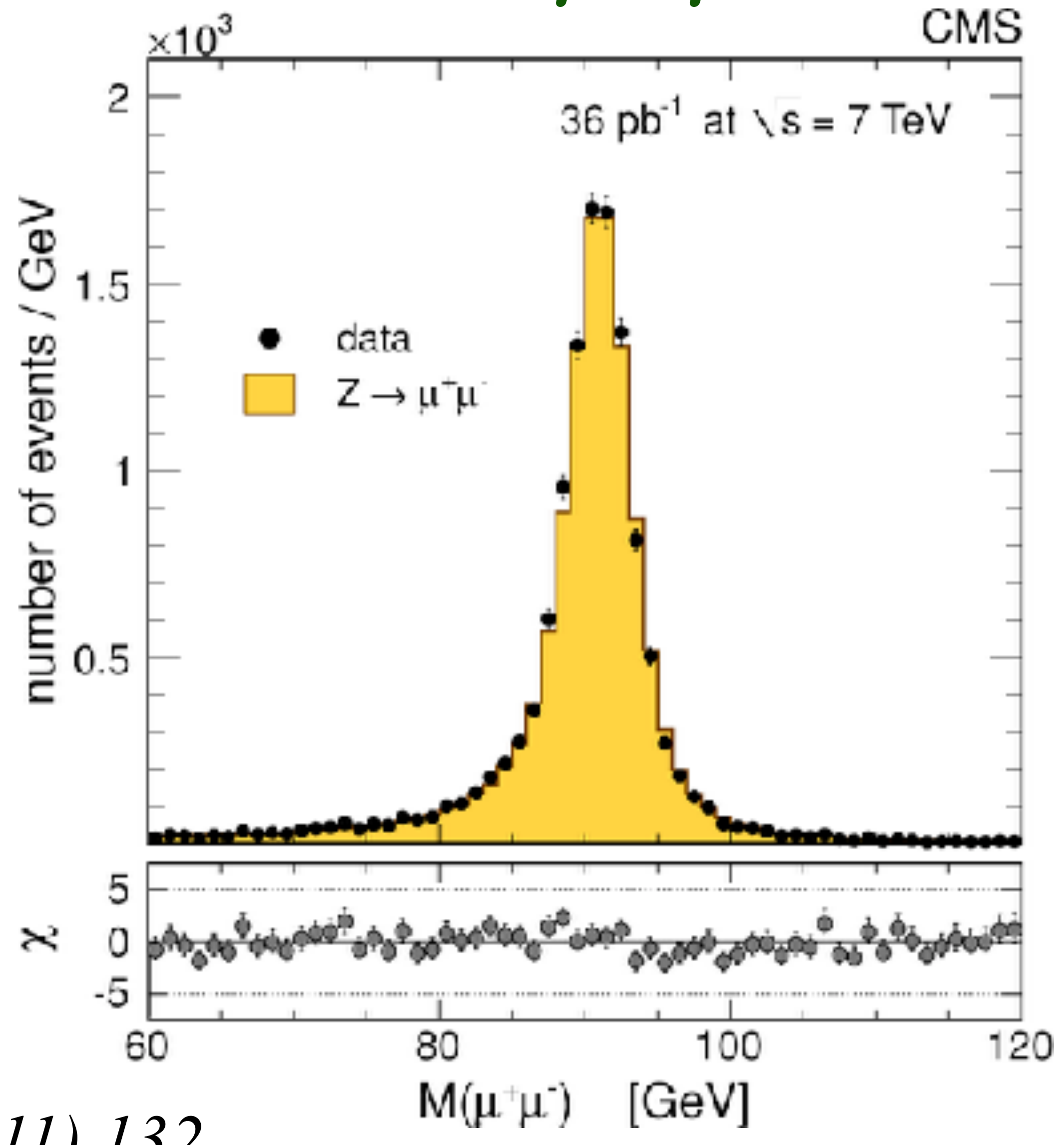
1. *A **very good** and **redundant muon system***
2. *The **best possible ECAL consistent with 1.***
3. *A **high quality central tracking** to achieve 1. and 2.*
4. *A **financially affordable** detector*

Muons are key signatures

$W^{\pm} \to \mu^{\pm}\nu_{\mu}$

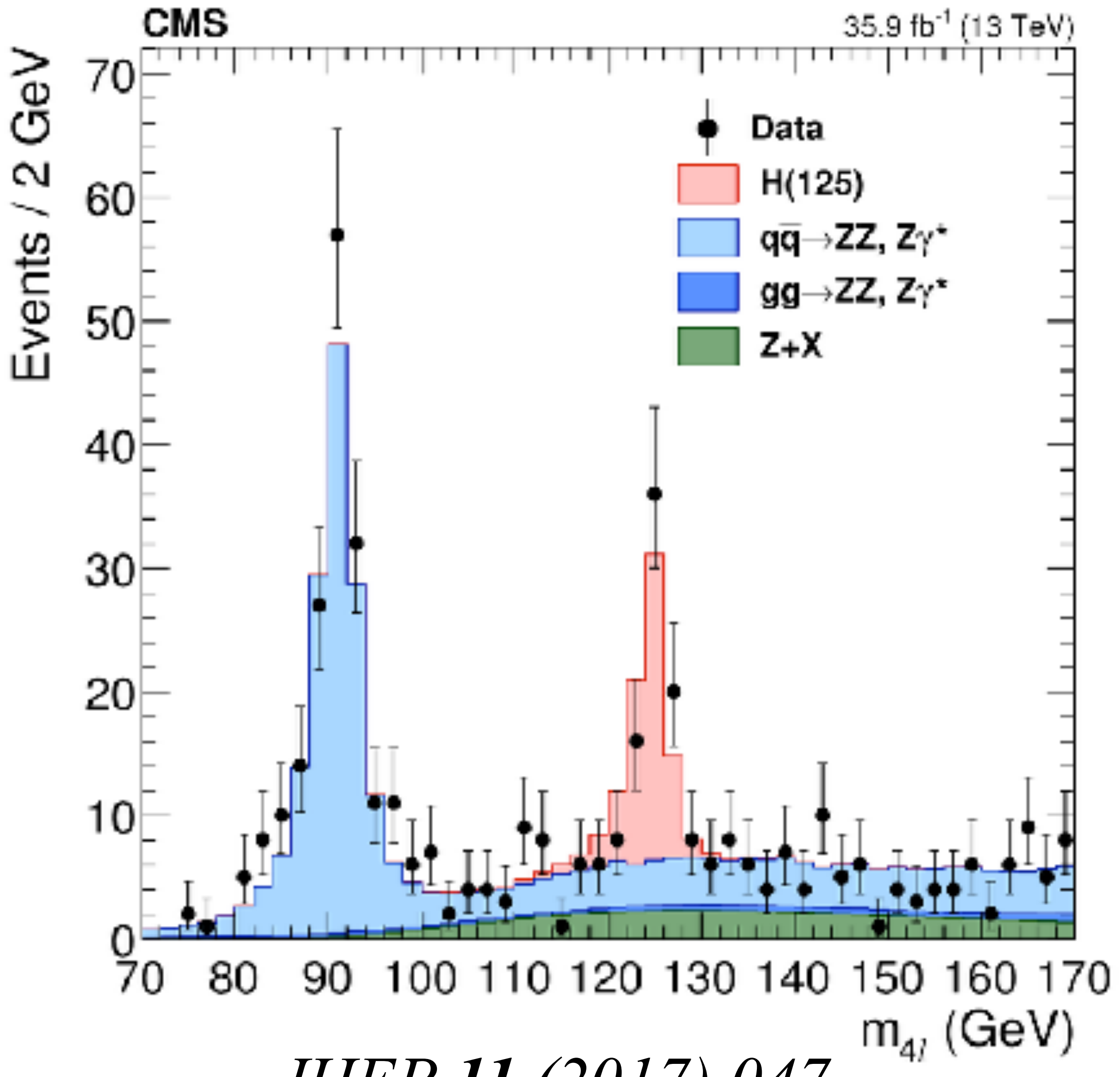


$Z \to \mu^{+}\mu^{-}$



JHEP ***10*** *(2011) 132*

$H \to ZZ^{*} \to \ell^{+}\ell^{-}\ell^{+}\ell^{-}$



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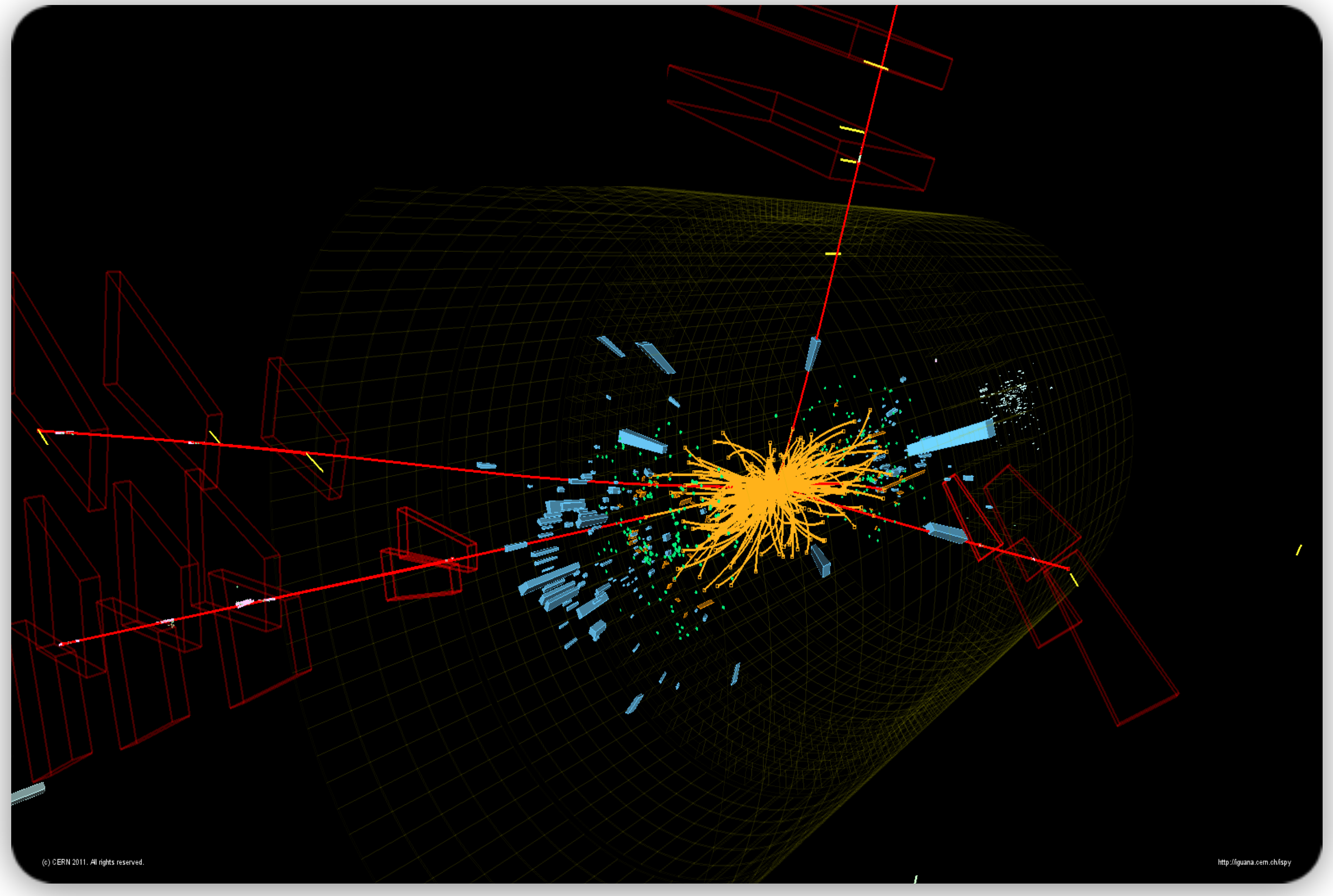
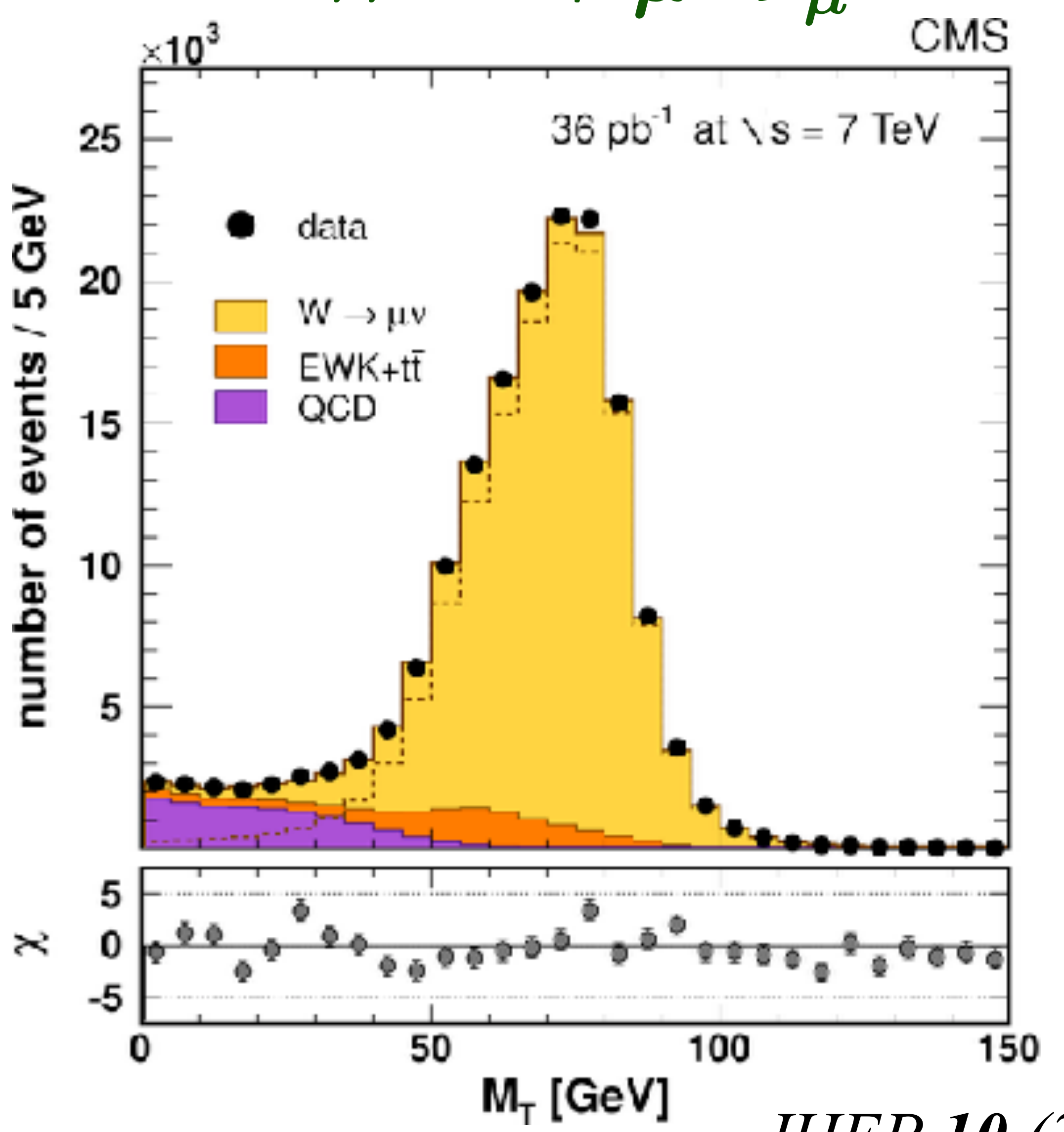
$H \to ZZ^{*} \to \mu^{+}\mu^{-}\mu^{+}\mu^{-}$



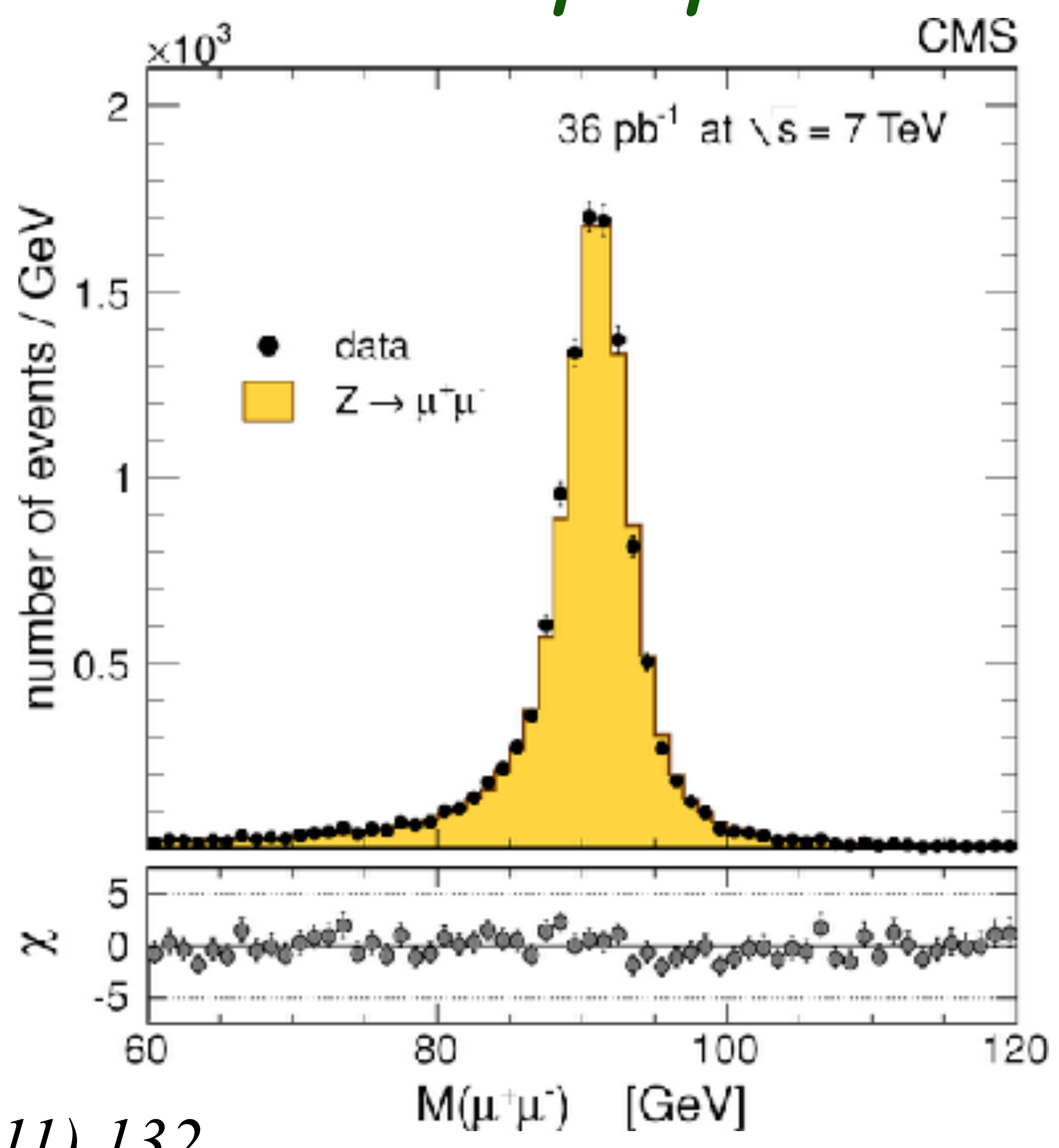
- Muons are **possibly the most important single particle at the LHC**
  - **Key to reconstruct SM particles** such as $W^{\pm}$, Z, or Higgs
  - **Key to searches for new physics.**

Muons are key signatures

$W^{\pm} \to \mu^{\pm}\nu_{\mu}$

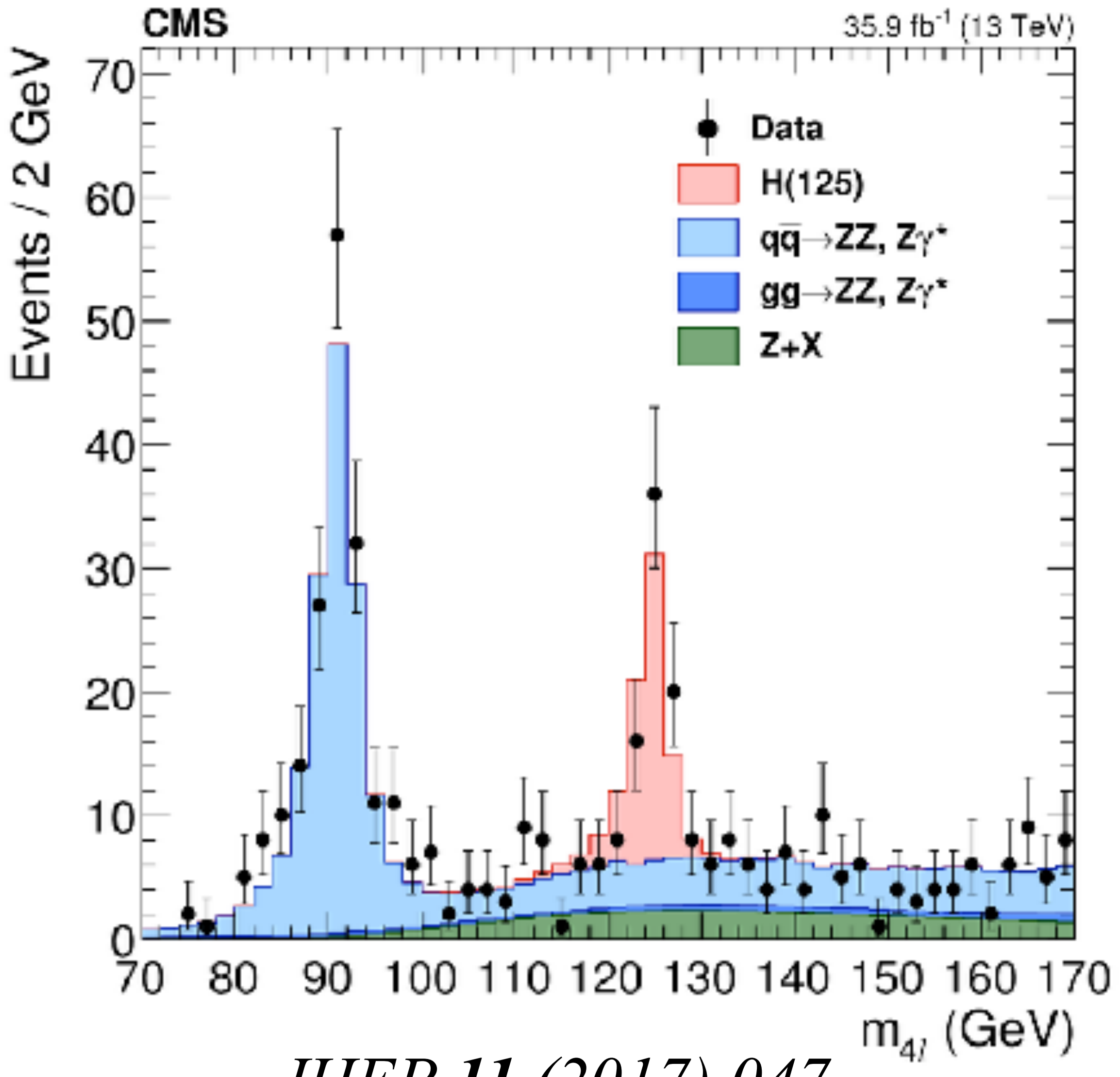


$Z \to \mu^{+}\mu^{-}$



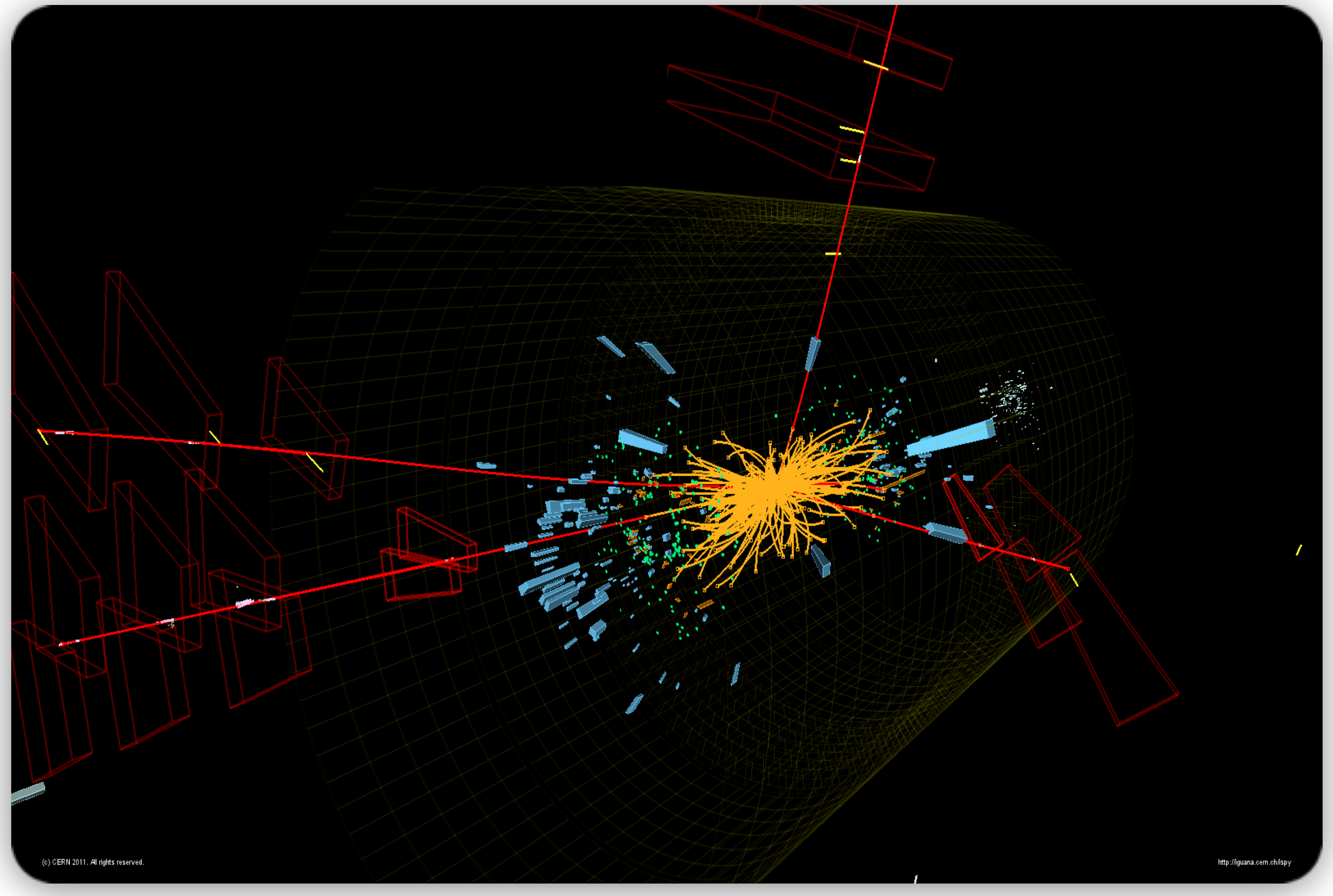
JHEP **10** (2011) 132

$H \to ZZ^* \to \ell^+\ell^-\ell^+\ell^-$



JHEP **11** (2017) 047

$H \to ZZ^* \to \mu^+\mu^-\mu^+\mu^-$



- Muons are **possibly the most important single particle at the LHC**
  - **Key to reconstruct SM particles** such as W±, Z, or Higgs
  - **Key to searches for new physics.**
- Electrons also have a clean signature, **how are muons better?**
  - eg, CMS has not been able to measure the denominator of the very interesting R(K*)

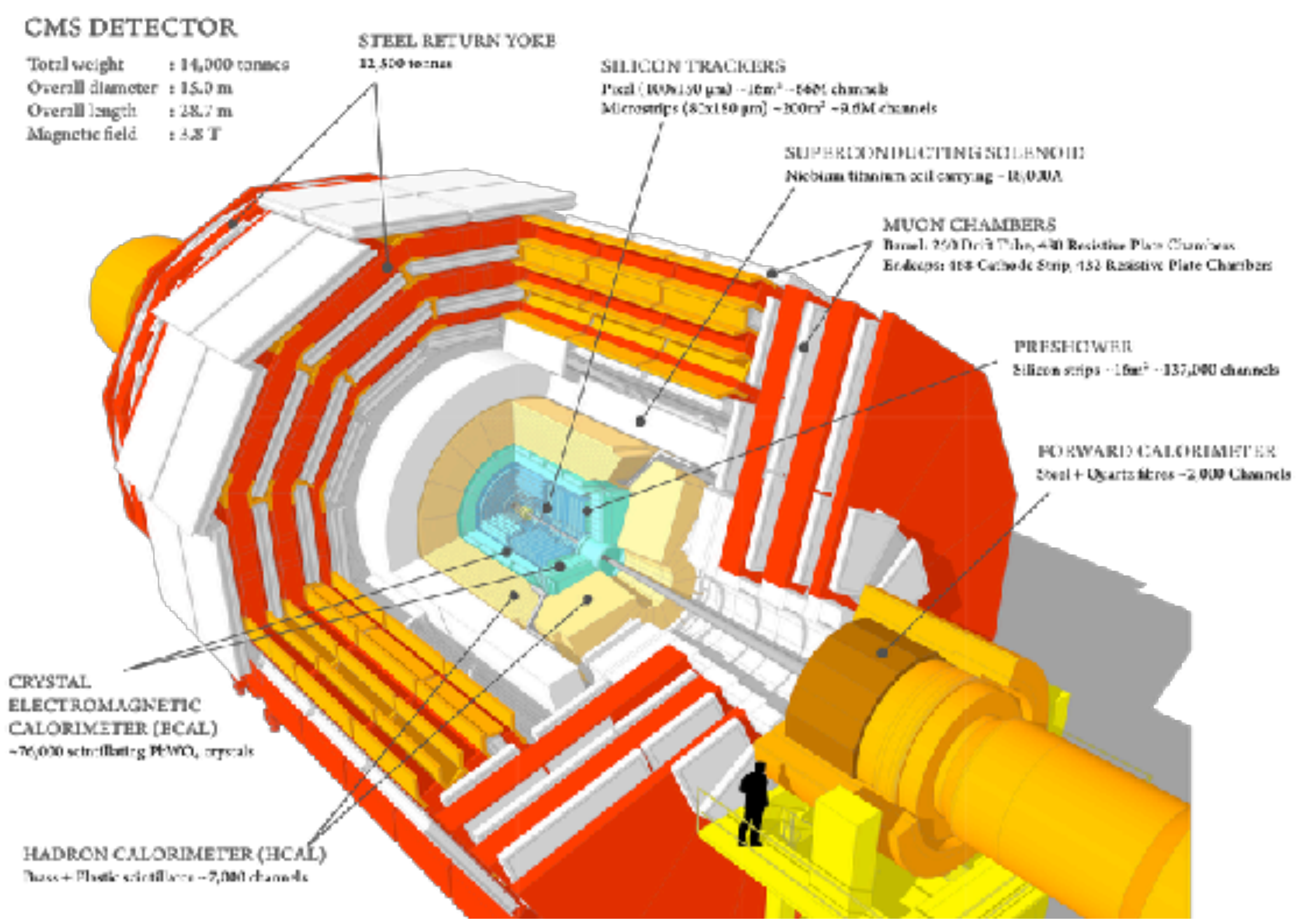
Easy

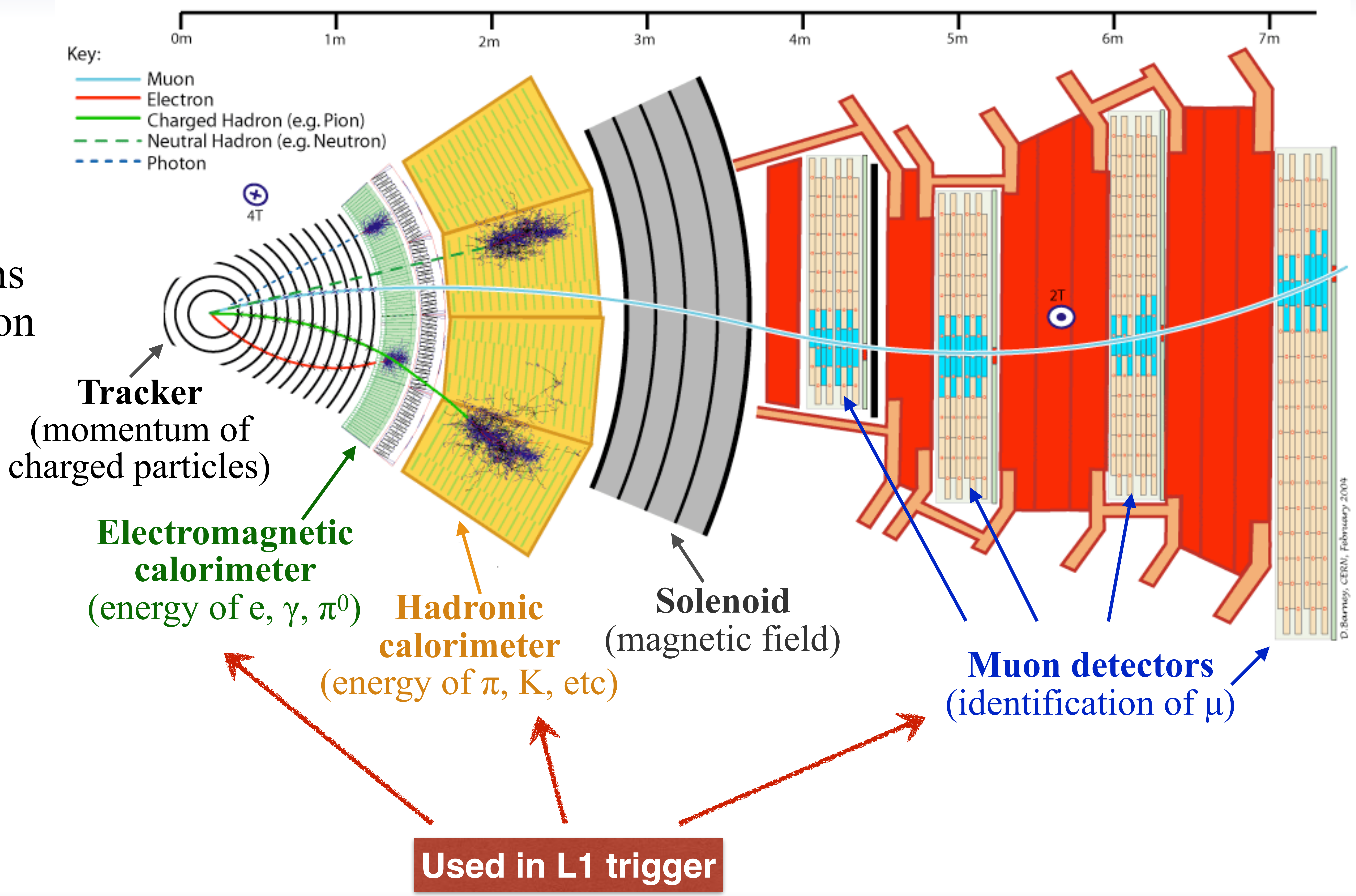
$$\mathscr{R}(K^*) = \frac{\boxed{\mathscr{B}(B \to K^*\mu^+\mu^-)}}{\boxed{\mathscr{B}(B \to K^*e^+e^-)}}$$

Difficult

Only CALO and MUON at L1

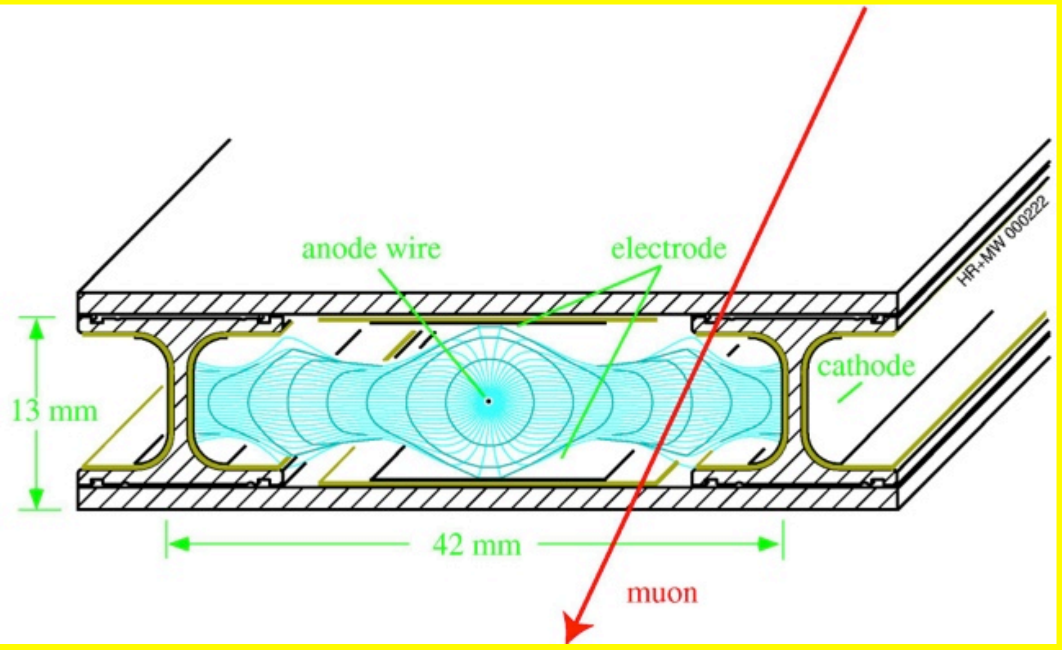
- L1 trigger only uses calorimeters and muon system
  - **Muons can be triggered more easily at L1 → lower p_T thresholds**
- Another difference is that electrons radiate more → worse p_T resolution





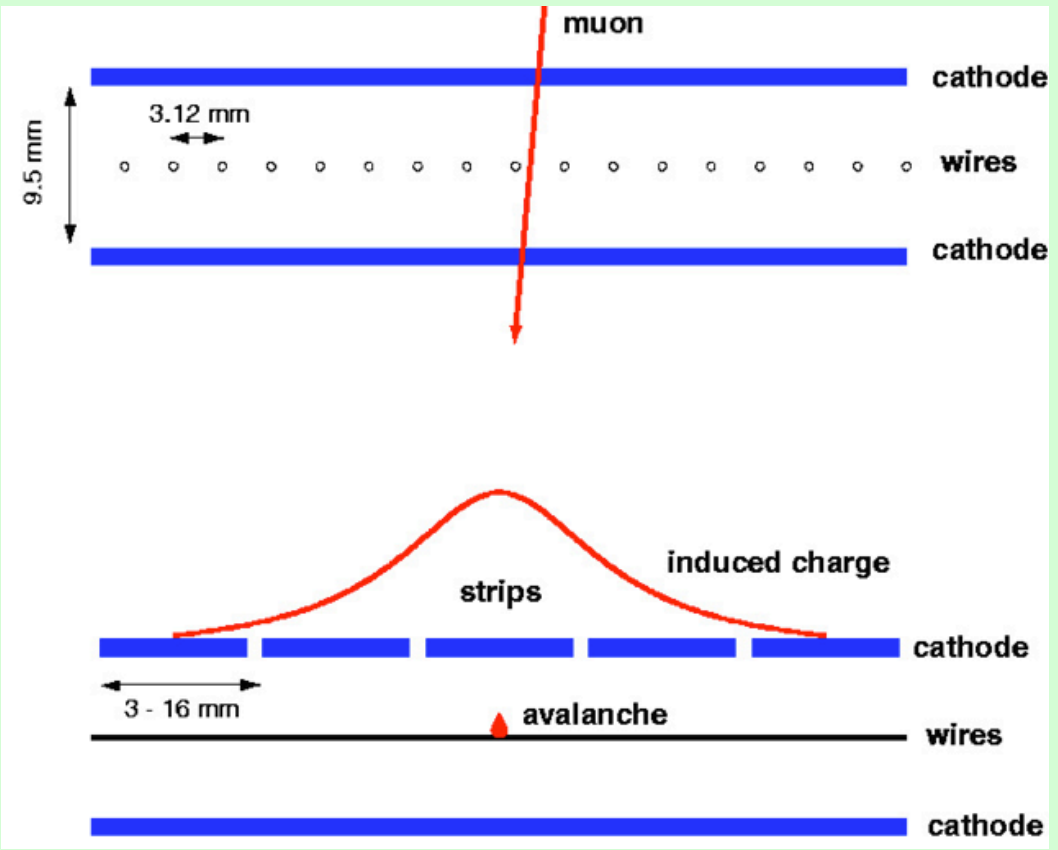
Technologies in CMS muon system

DTs



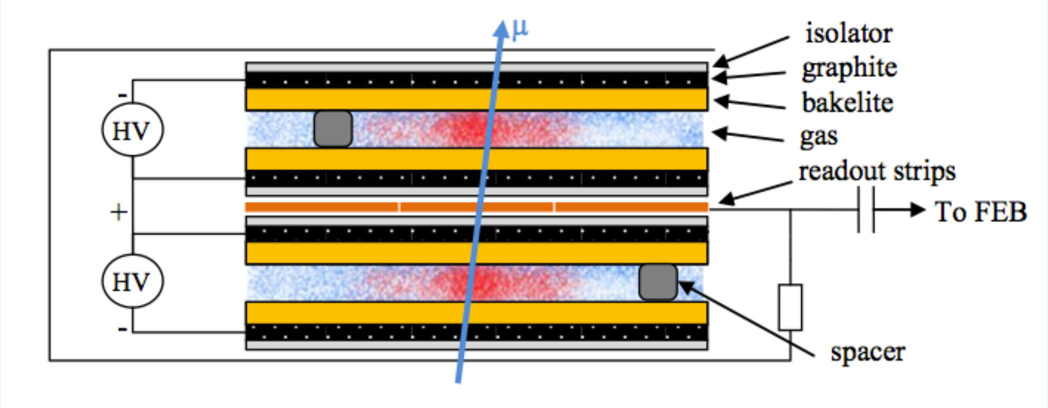
Sensitive layers area: **18,000 m²**
Number of channels: **172K**

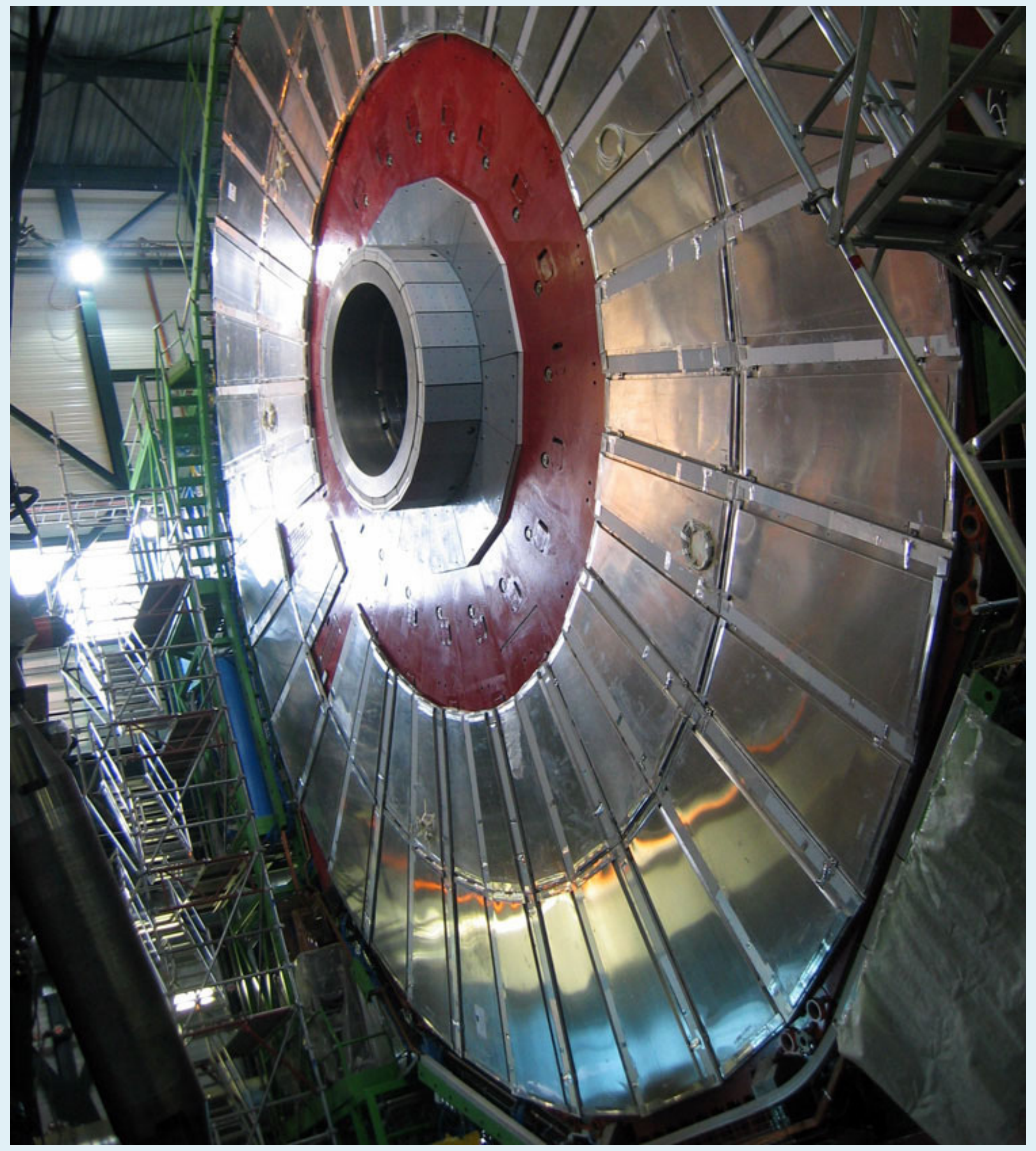
CSCs



Sensitive layers area: **7,000 m²**
Number of channels: **477K**

RPCs

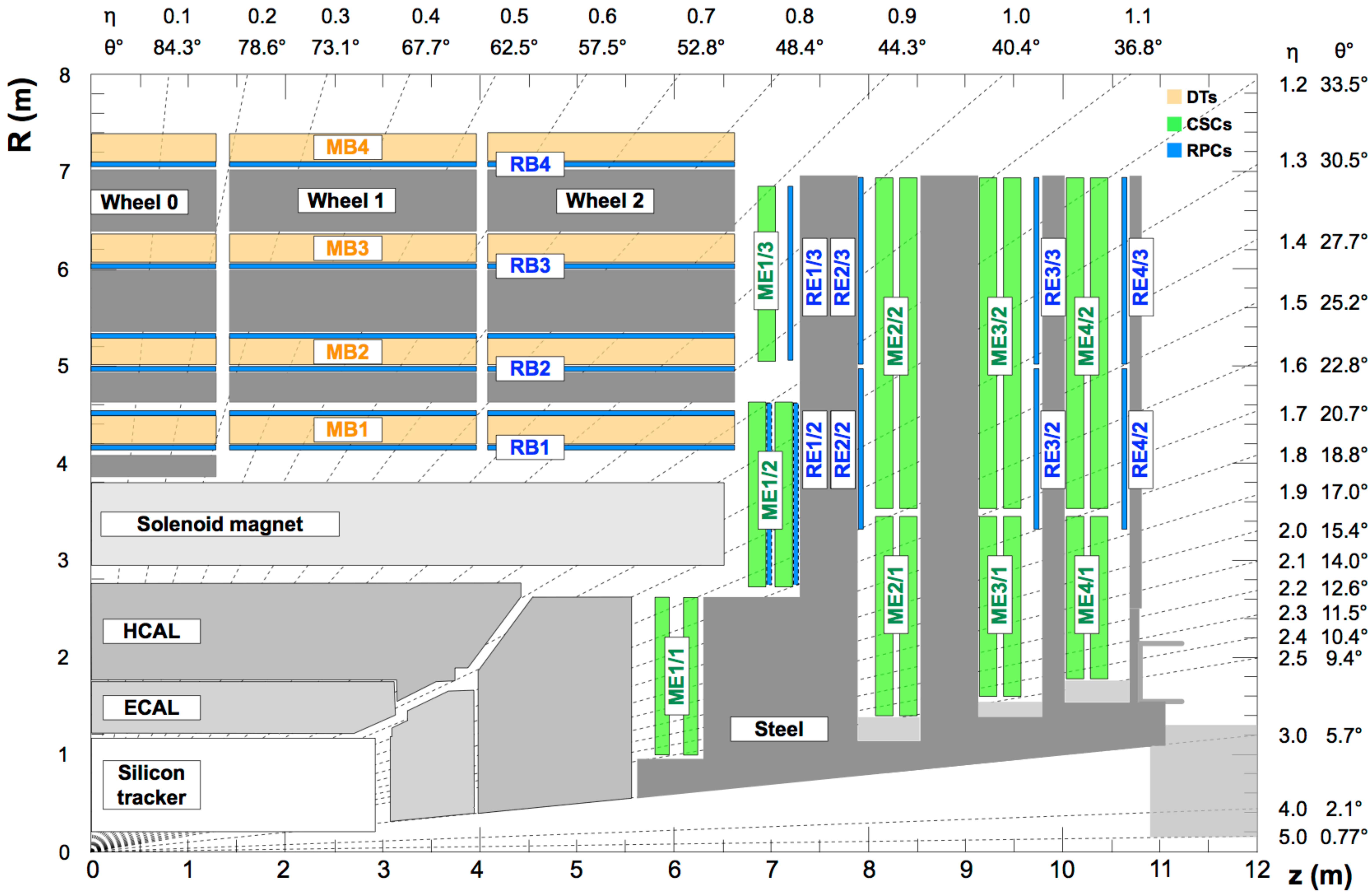




Sensitive layers area: **3,200 m²**
Number of channels: **123K**

- **Drift tubes (DTs)**
  - Precise
  - Cheap to cover large areas
  - Original cost $22.3M
- **Cathode strip chambers (CSCs)**
  - Precise
  - Capable on handling high rates, irregular magnetic field
  - Original cost $28.8M
- **Resistive plate chambers (RPCs)**
  - Cheap
  - Fast
  - Original cost $7.0M

CMS muon system



DT (drift tubes):
trigger, precision, low rate

CSC (cathode strip chambers):
trigger, precision, high rate

RPC (resistive plate chambers):
trigger, fast

Redundancy (4 stations with 2 detector technologies on the path of a muon in nearly all directions) ensures

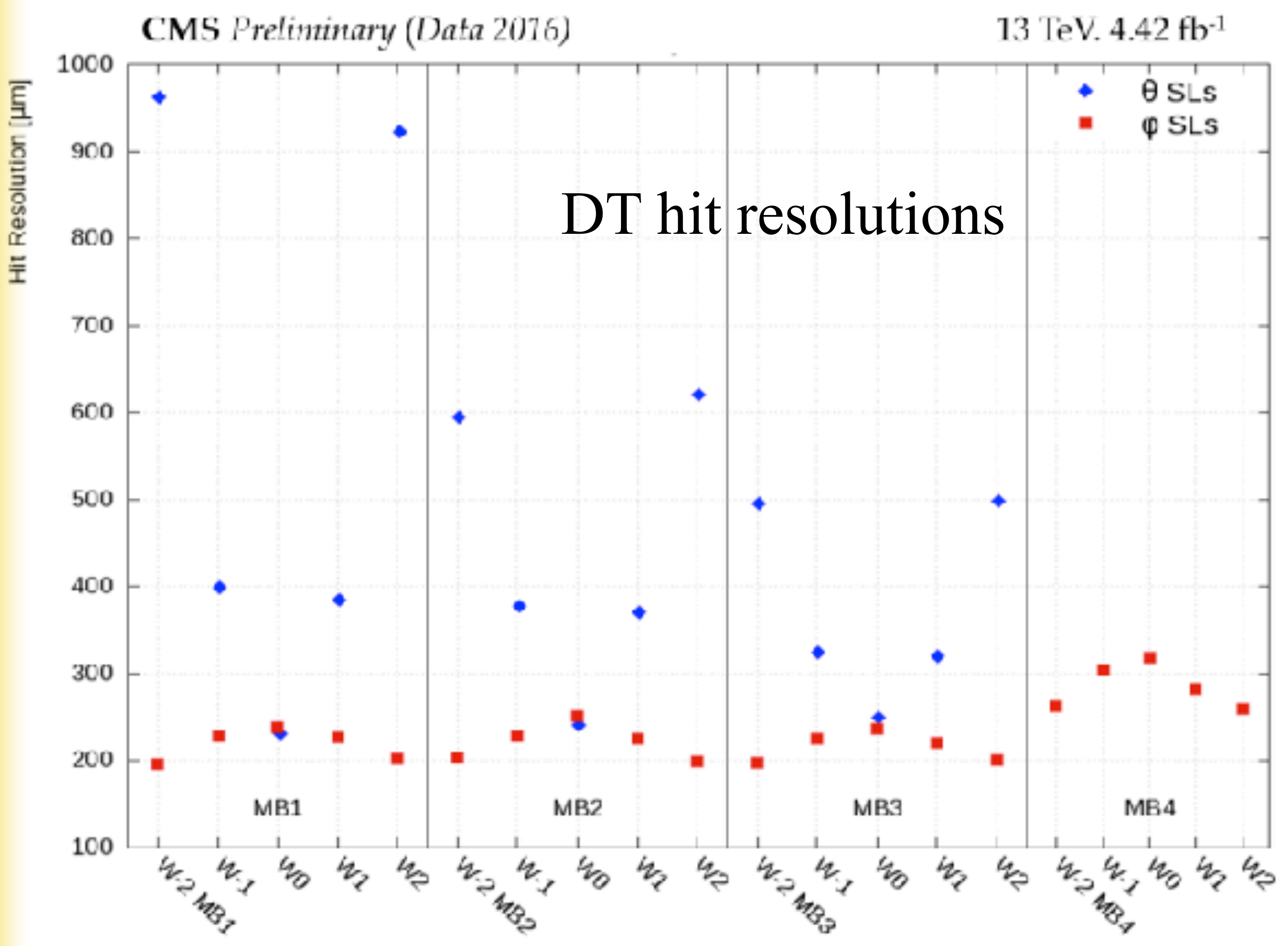
- robust trigger
- efficient reconstruction

Offline spatial/timing resolution

DT

$\sigma_{\text{hit}}^{\phi} \sim 200 - 250\,\mu m$

$\sigma_{\text{timing}} \sim 2$ ns



CSC

$\sigma_{\text{hit}}^{\phi} \sim 120 - 350\,\mu m$

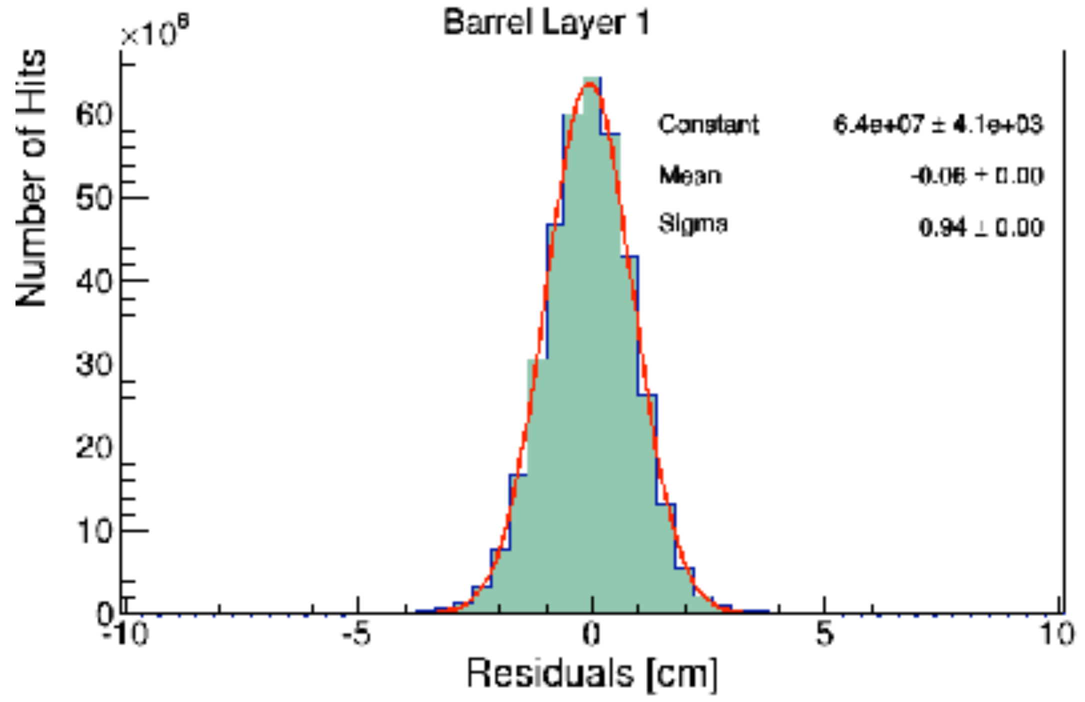
$\sigma_{\text{timing}} \sim 3$ ns

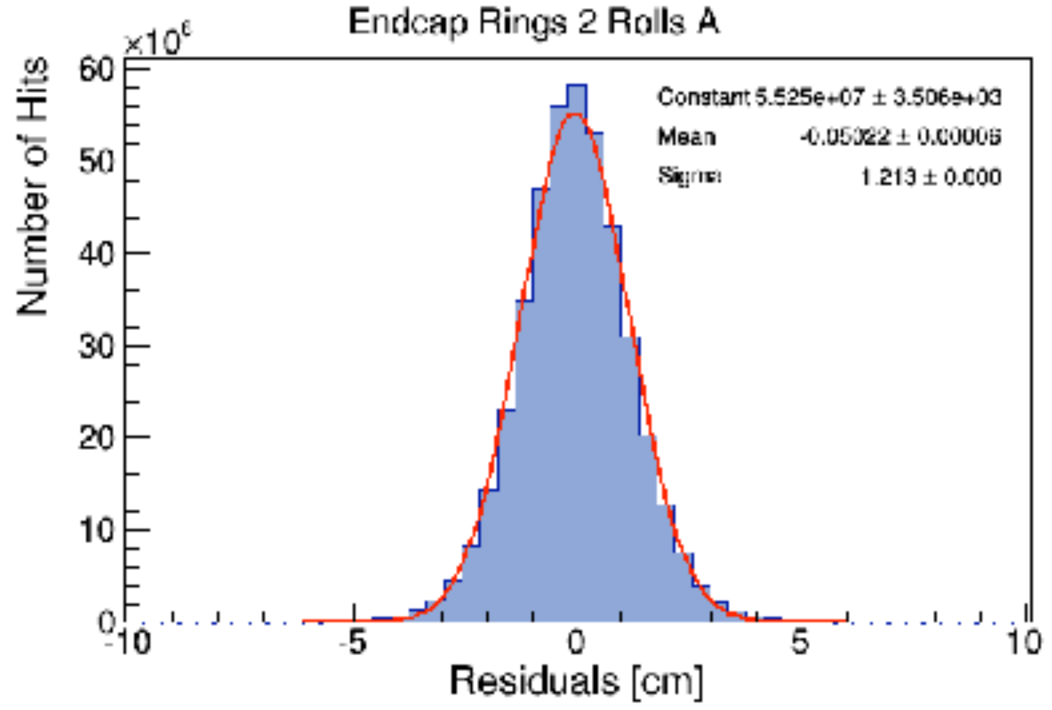
Approximate CSC hit resolutions

[µm]	2012	2015
ME1/1a	160	120
ME1/1b	140	130
ME1/2	230	230
ME1/3	265	270
ME2/1	325	320
ME3/1	305	305
ME4/1	310	315
ME2/2	345	350
ME3/2	350	350
ME4/2	360	350

RPC

$\sigma_{\text{hit}}^{\phi} \sim 940 - 1{,}500\,\mu m$

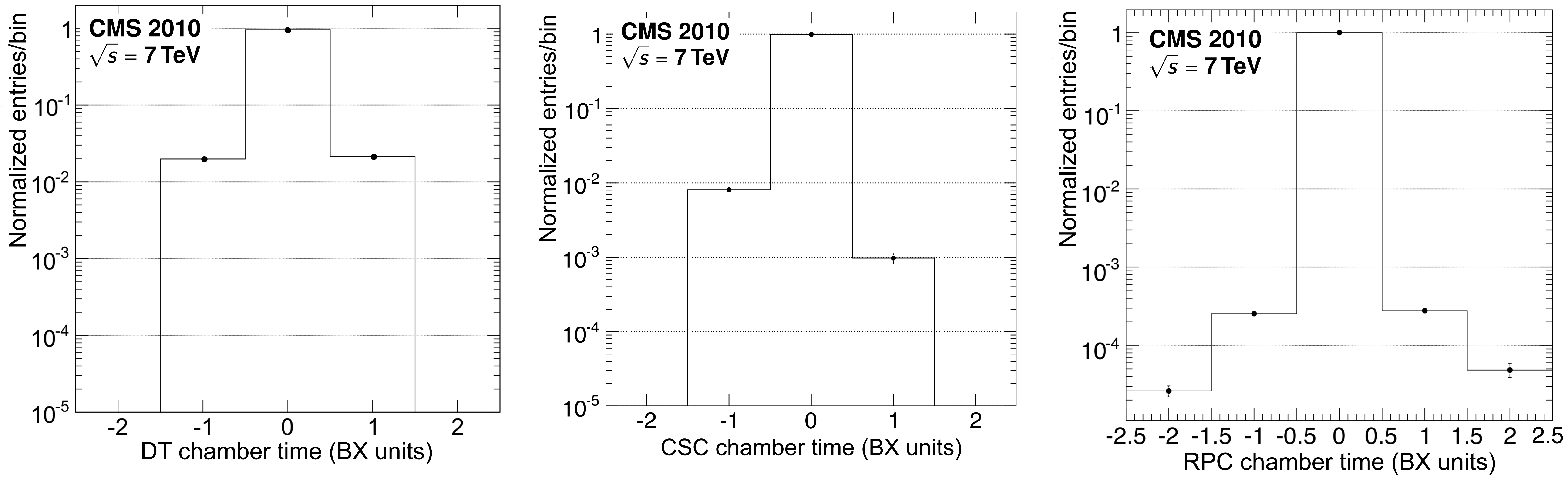




Role of RPCs

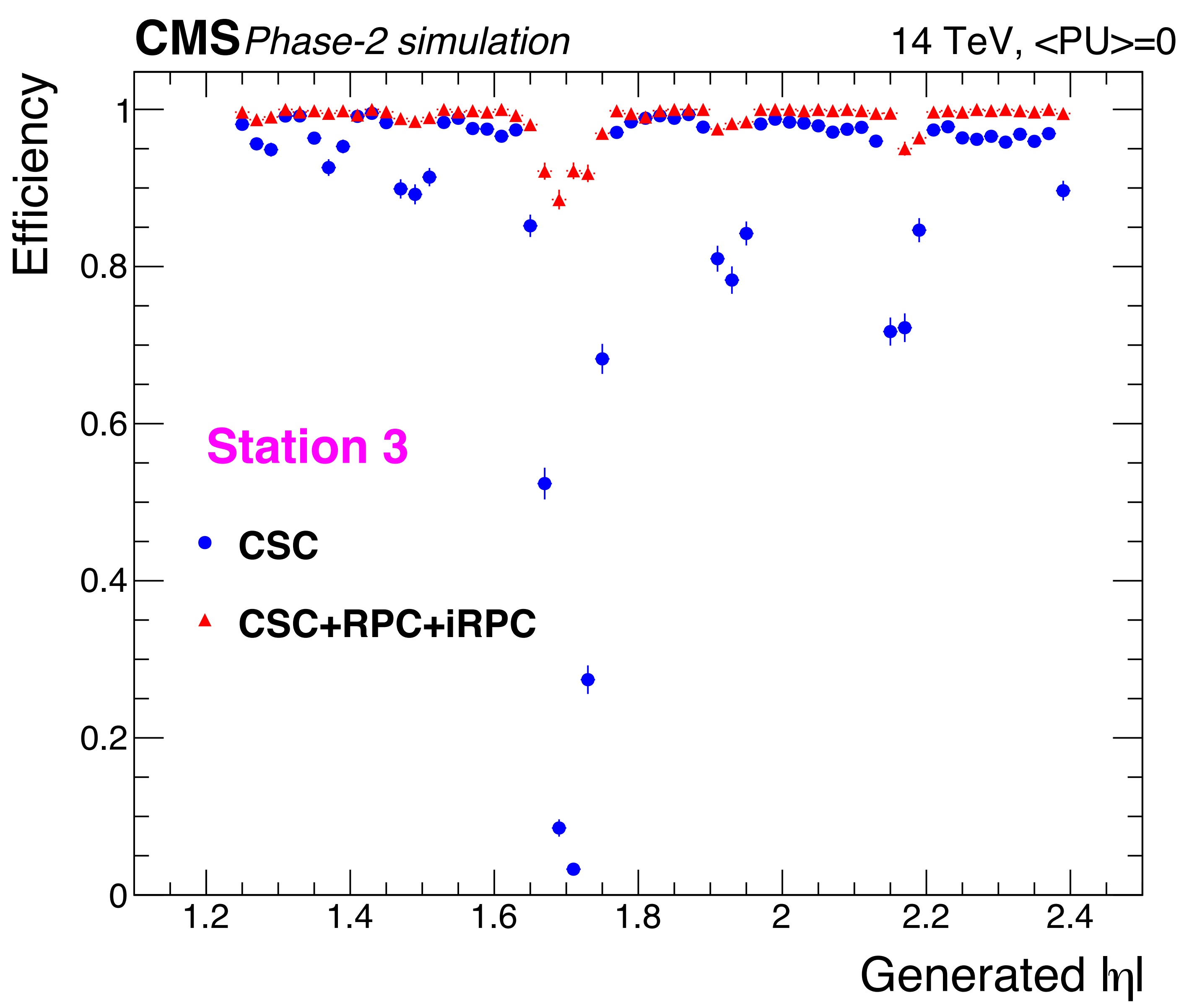
Online identification of μ bunch crossing (BX)

DTs and CSCs identify the right BX ~ 98% of the time
RPCs identify the right BX ~ 99.8% of the time

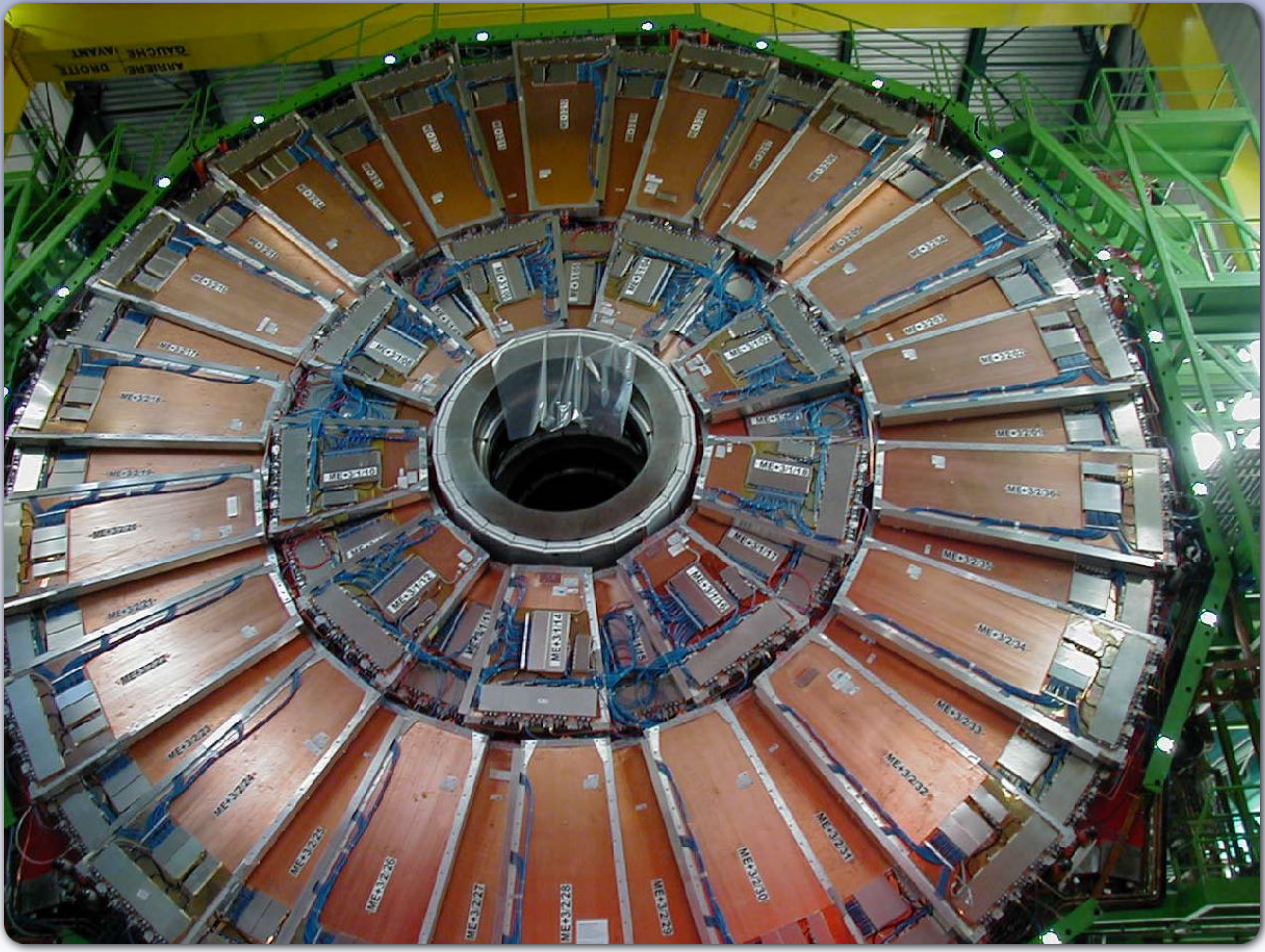


Redundancy in gaps

Gaps between CSC/DT rings and HV segments are covered by RPCs



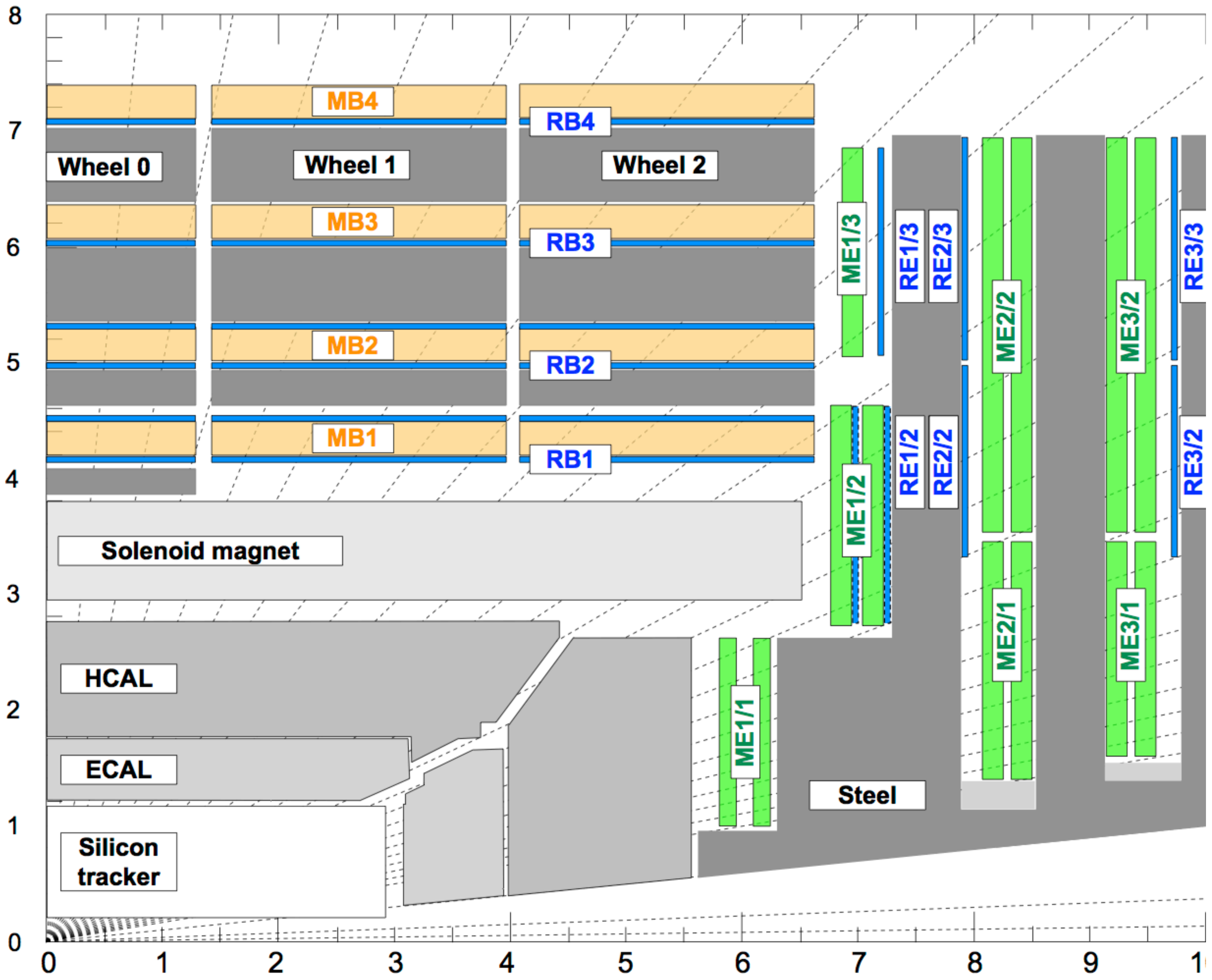
Chamber nomenclature

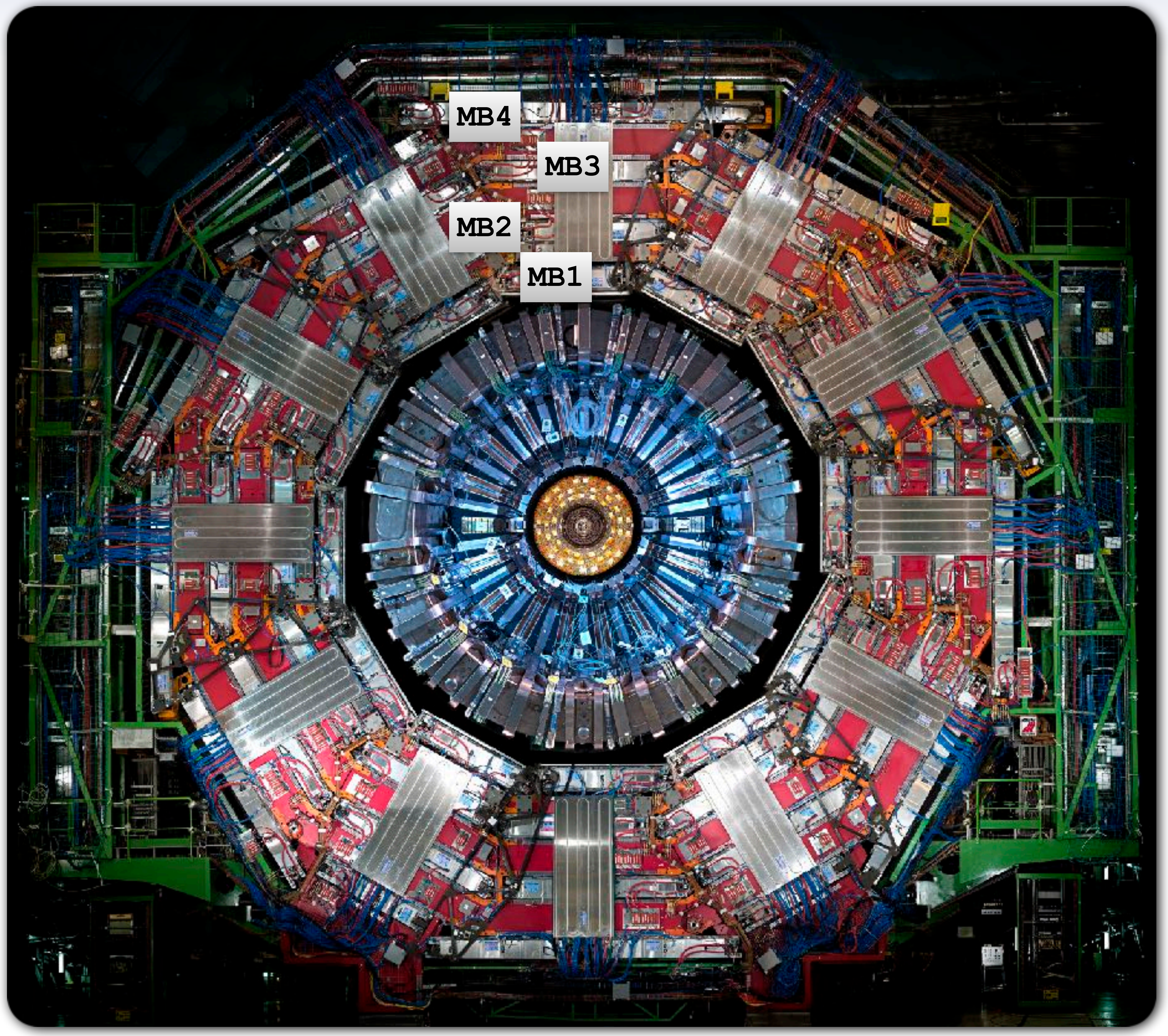


DT nomenclature

Muon Barrel Station

MB1±2 ← **Wheel**

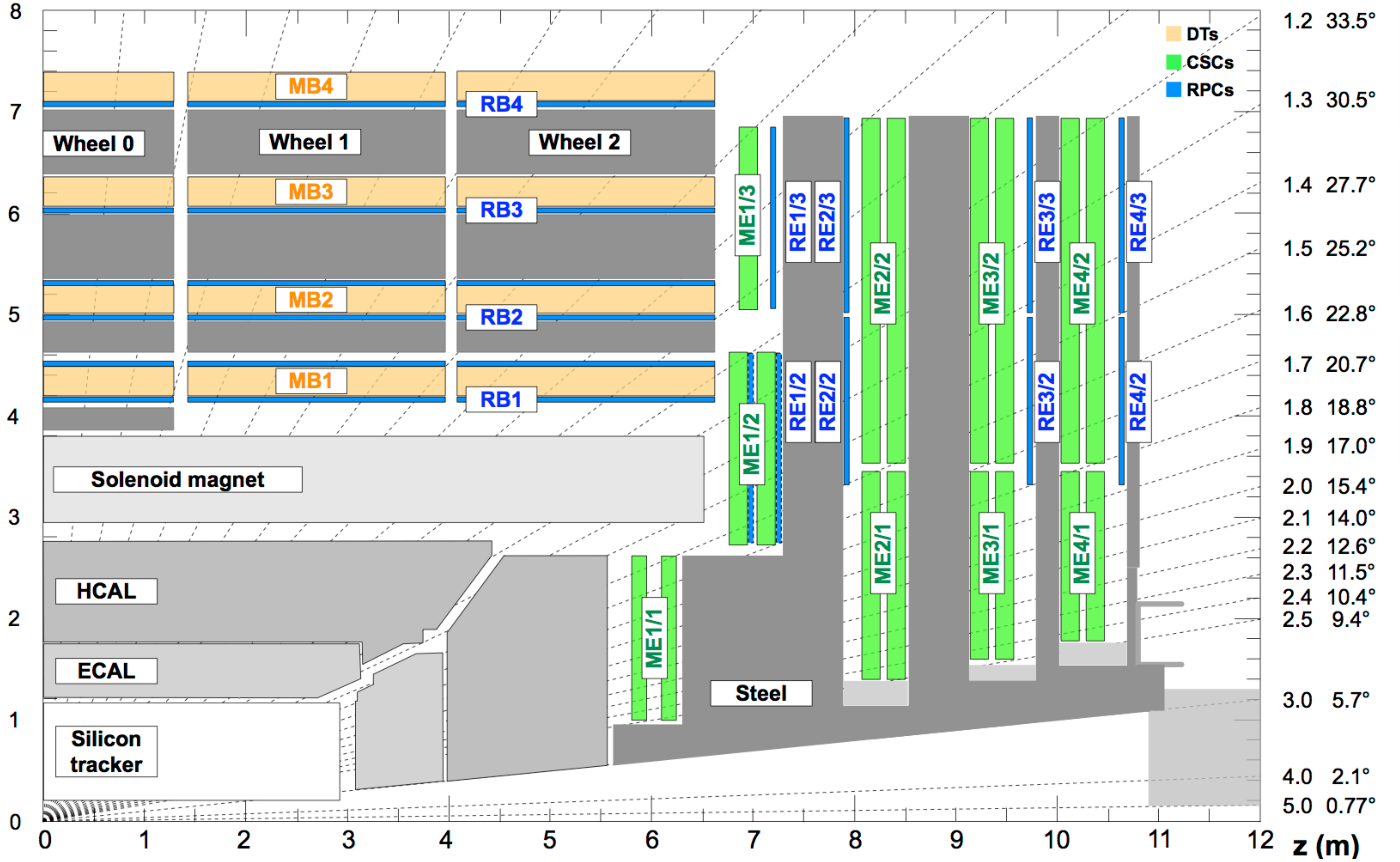


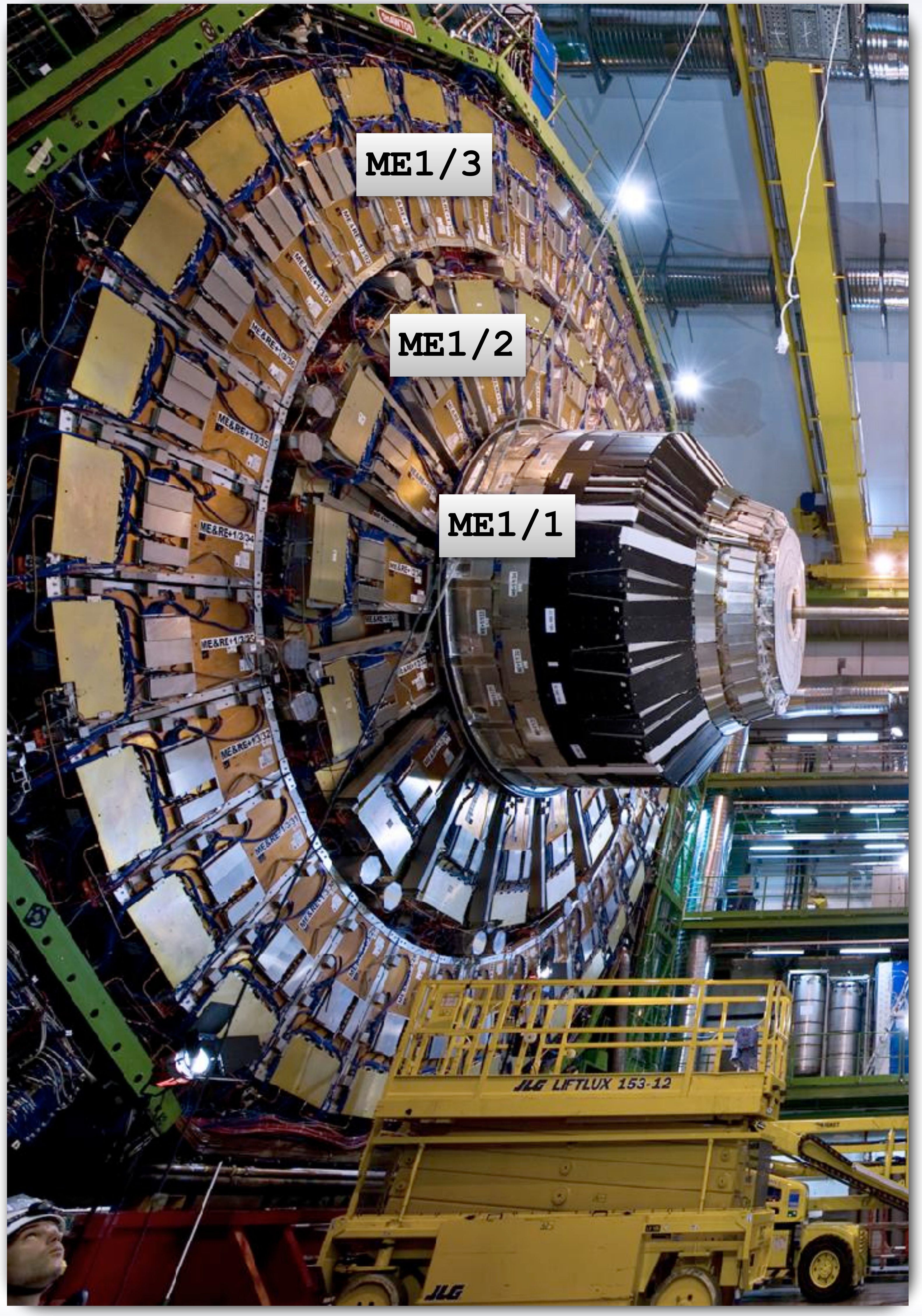


CSC nomenclature

Muon Endcap Station Ring

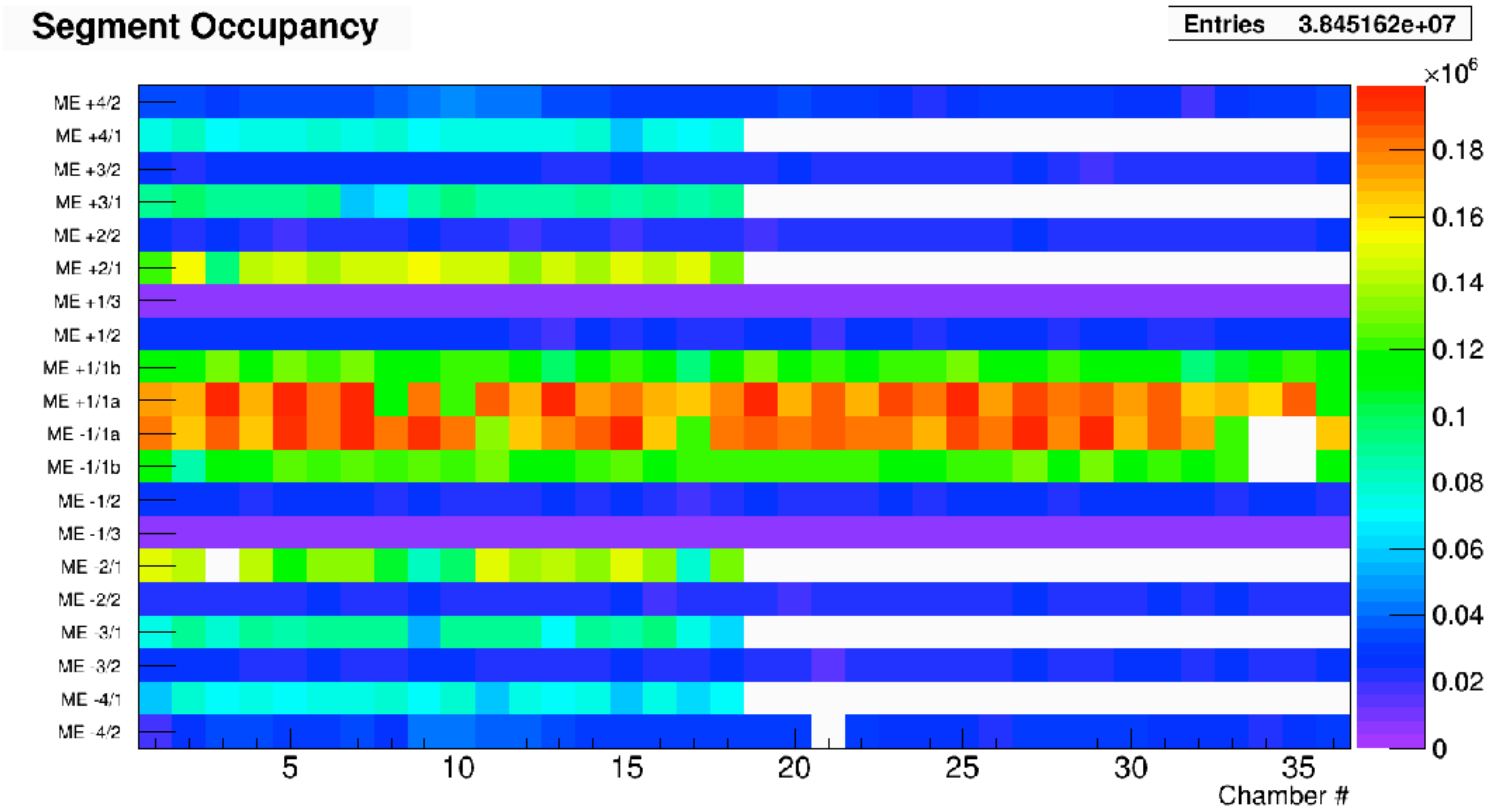
ME2/1



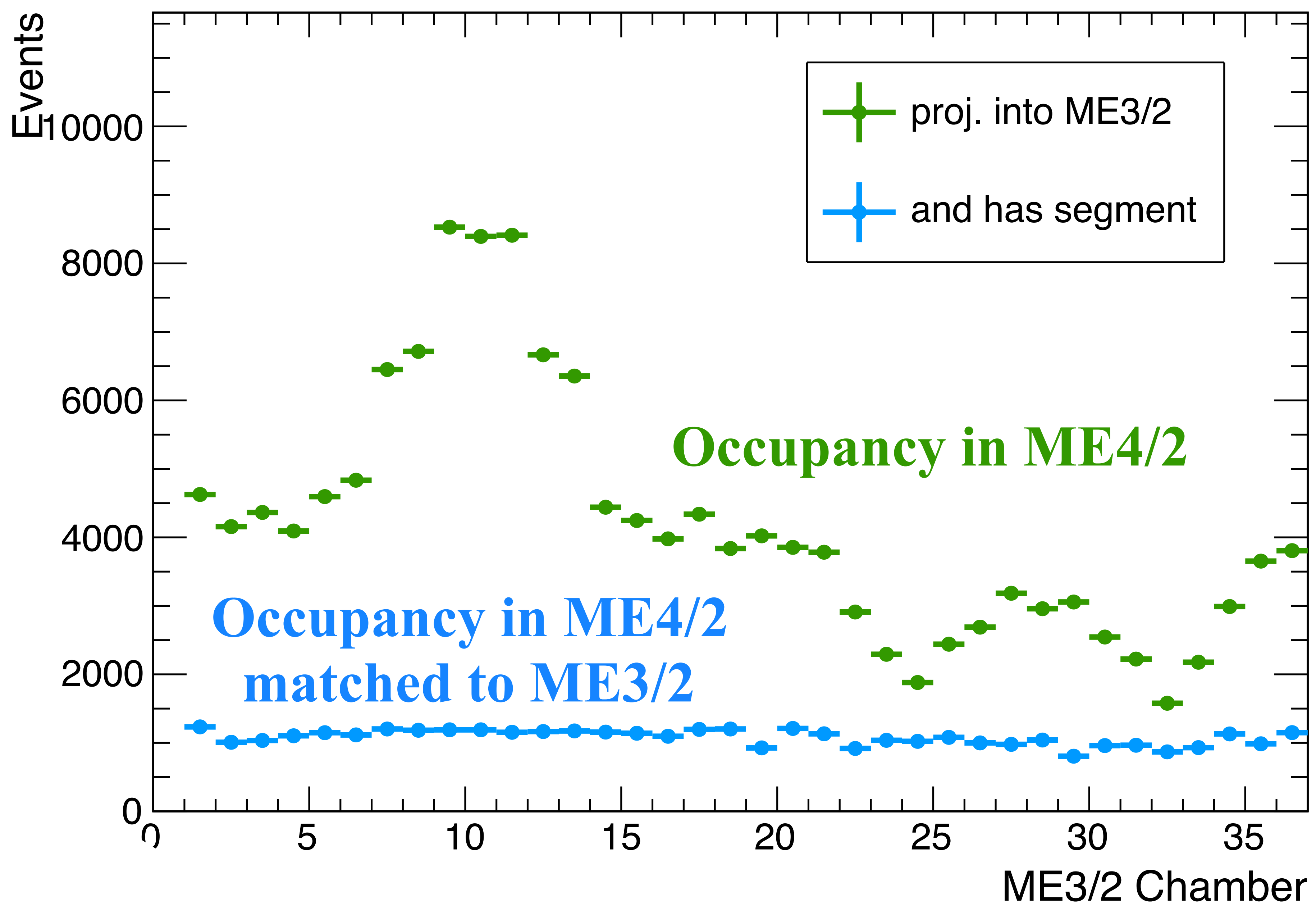


Extended CSC nomenclature

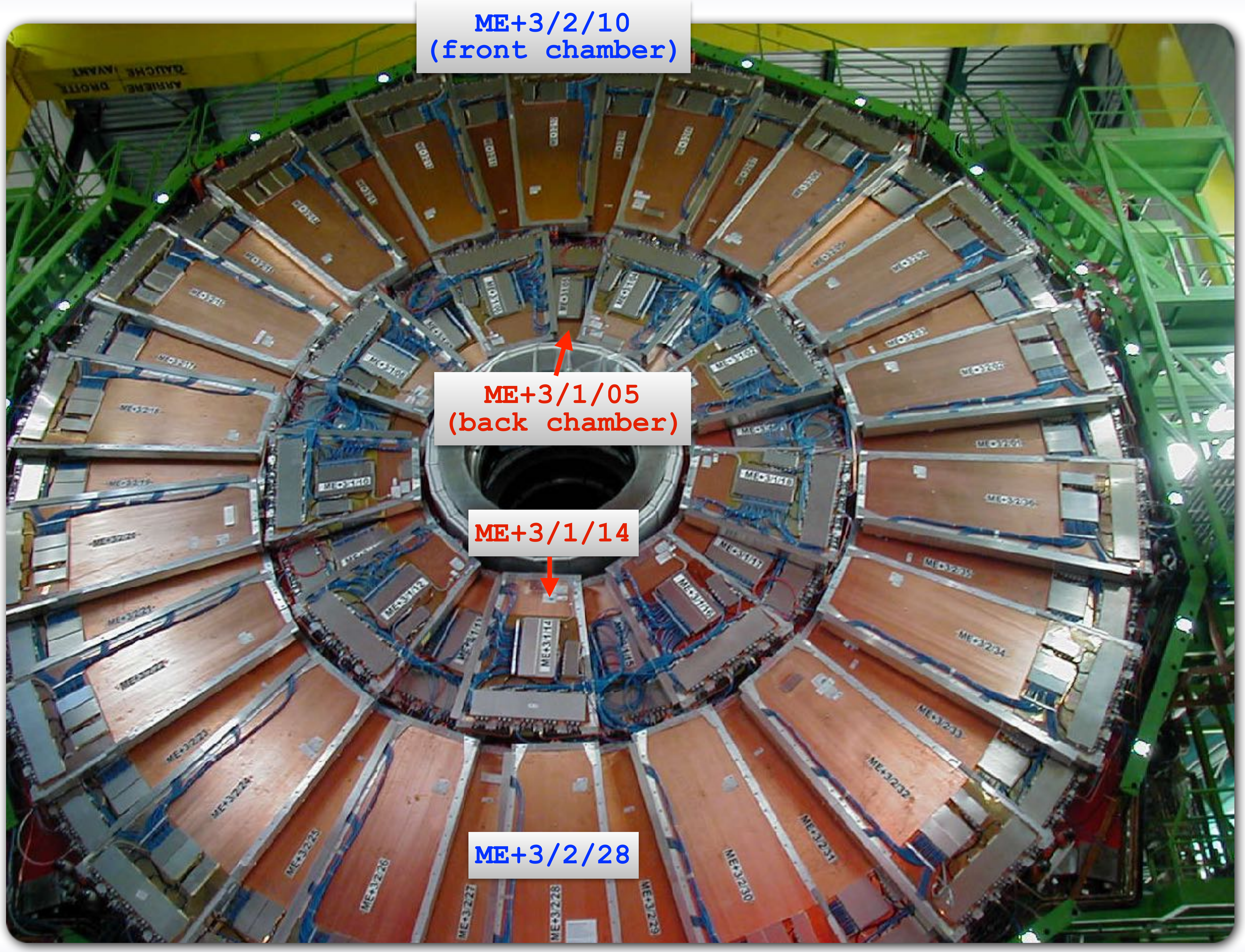
- Very common to see plots in terms of **Chamber number**
  - Important to know geometrically where they are located



Famous plot made by Nick Amin studying the **beam background** that we see **in ME4/2** that does not reach ME3/2



Extended CSC nomenclature



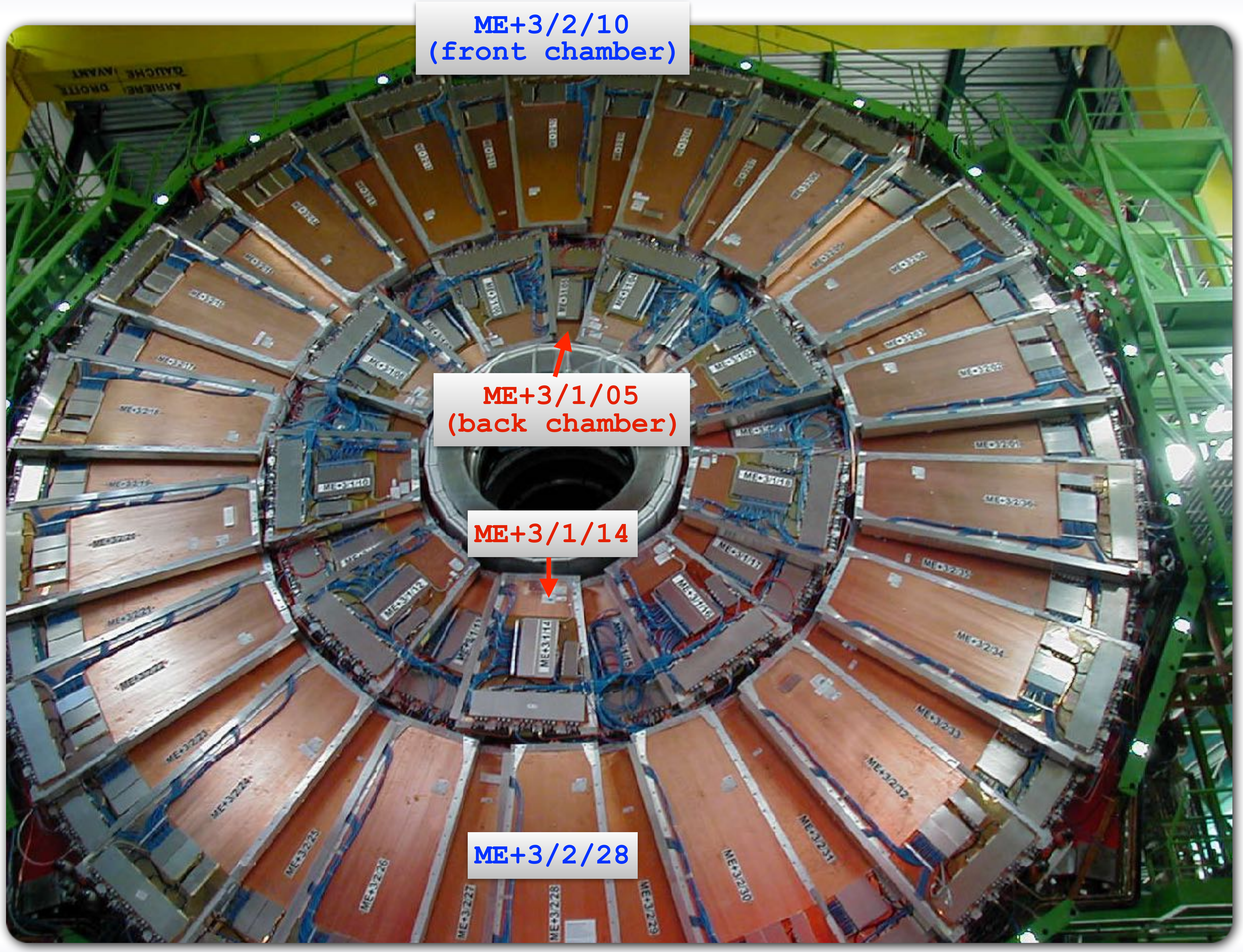
Muon Endcap plus/minus endcap

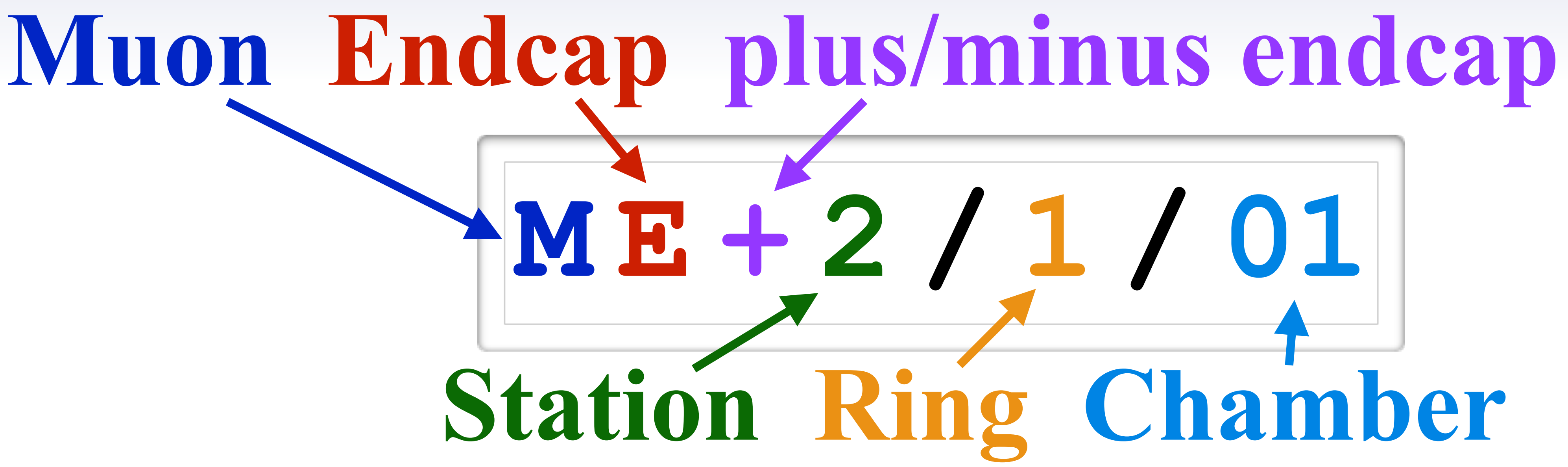
ME+2/1/01

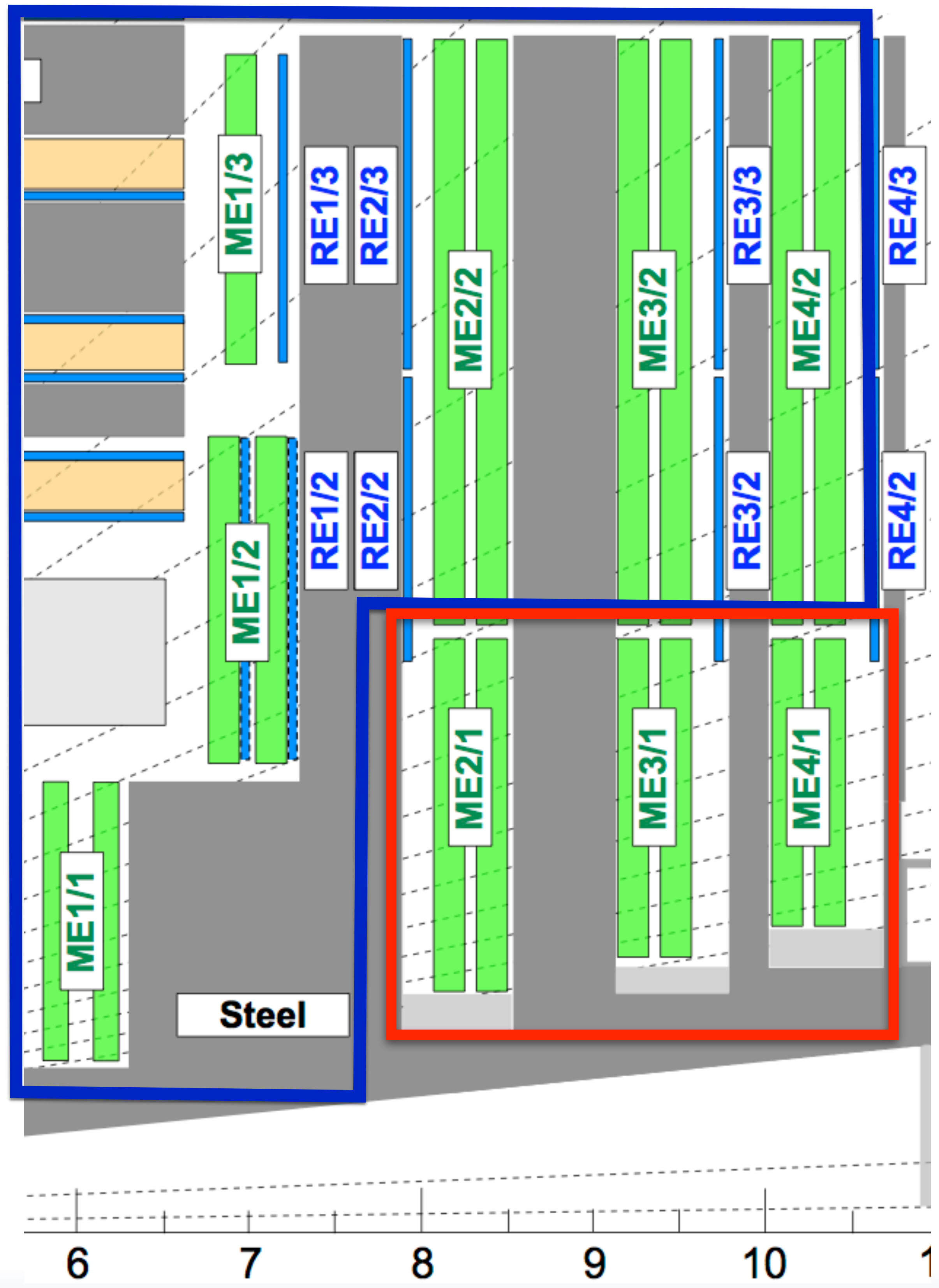
Station Ring Chamber

Front and **back chambers are staggered** so that the active areas overlap in ϕ, thus forming a **seamless ring**

Extended CSC nomenclature



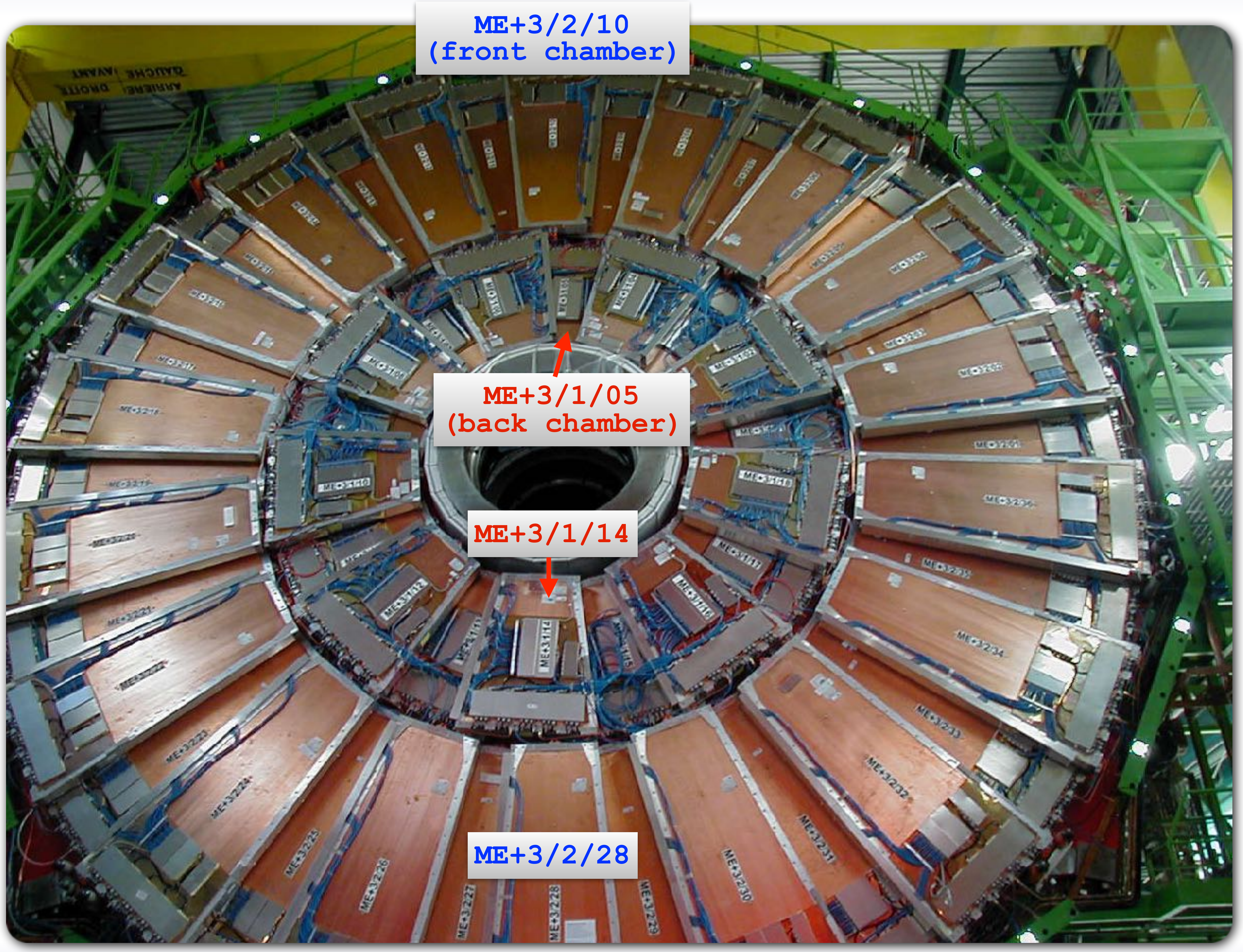




ME1/1, ME1234/2, and ME1/3 have **36 chambers per ring** (10 degree-chambers)

ME234/1 have **18 chambers per ring** (20 degree-chambers)

Extended CSC nomenclature



Muon Endcap plus/minus endcap

ME+2/1/01

Station Ring Chamber

- **Quiz** (answers in backup)
  - How many chambers in ME-2?
  - How many chambers in ME3/1?
  - How many chambers in ME1?
  - How many CSCs in total?

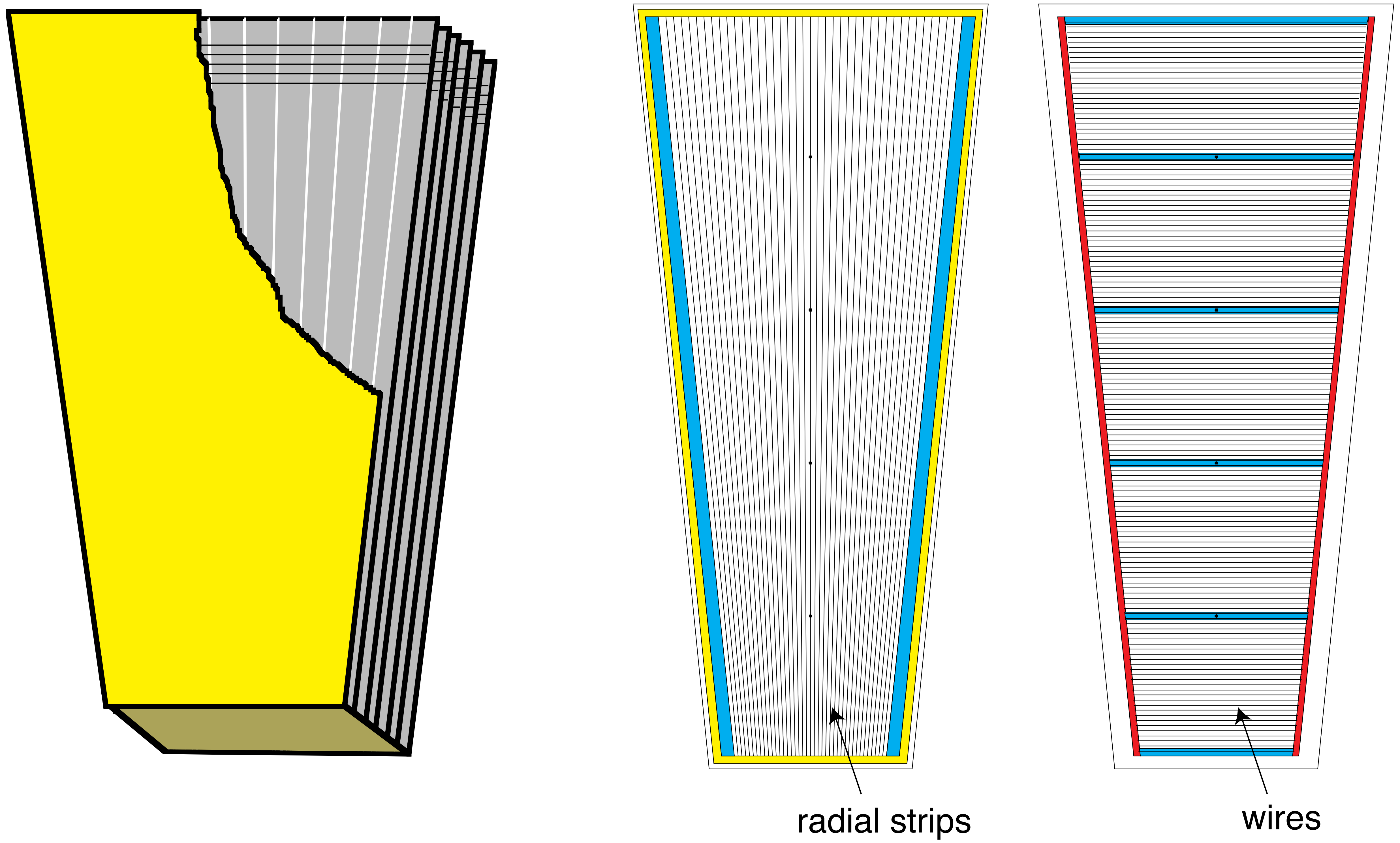
Cathode Strip Chambers

Cathode strip **chamber**

- The CSCs in CMS have **six independent layers** that measure points (hits) along the trajectory of muons
  - Seven cathode panels forming **six gas gaps** (6 mm in ME1/1, 9.5 mm elsewhere)
  - **Six** of the the **cathode panels** are **segmented into radial strips** (measure φ accurately)
  - Also, **six wire layers (anodes)** in the middle of each gas gap running transversally

Open ME2/1 CSC being inspected at PNPI

6 strip-wire layers running orthogonally in each CSC



Chamber parameters

Parameter	ME1/1	ME1/2	ME1/3	ME2/1	ME3/1	ME4/1	ME234/2
Basic single plane parameters							
full gas gap (2h), mm	6			9.5			
wire diameter, μm	30			50			
wire spacing, mm	2.5	3.16	3.16	3.12	3.12	3.12	3.16
Active area							
width (top), mm	487	819	933	1254	1254	1254	1270
width (bottom), mm	201	511	630	534	617	685	666
length, mm	1505	1635	1735	1900	1680	1500	3215
Wires							
wire tilt	25°			0°			
wires per plane	600	528	560	620	550	492	1028
wires per wire group	11-12	11	12	5, 6	5, 6	5	16
wire group width, mm	27.5-30	35	38	16, 19	16, 19	16	51
wire group cap., pF	60-150	40-70	50-80	20-60	20-60	25-45	80-150
wire channels per plane	48	48	48	112	96	96	64
Strips							
Δφ(single strip), mrad	2.96	2.33	2.16	4.65	4.65	4.65	2.33
width (top), mm	7.6	10.4	14.9	15.6	15.6	15.6	16.0
width (bottom), mm	3.15	6.6	11.1	6.8	7.8	8.6	8.5
gap between strips, mm	0.35			0.5			
strip capacitance, pF	90-140	110	145	145	130	120	250
radial split of strips	@η=2.0			none			
strip channels per plane	2x64	80	64	80	80	80	80

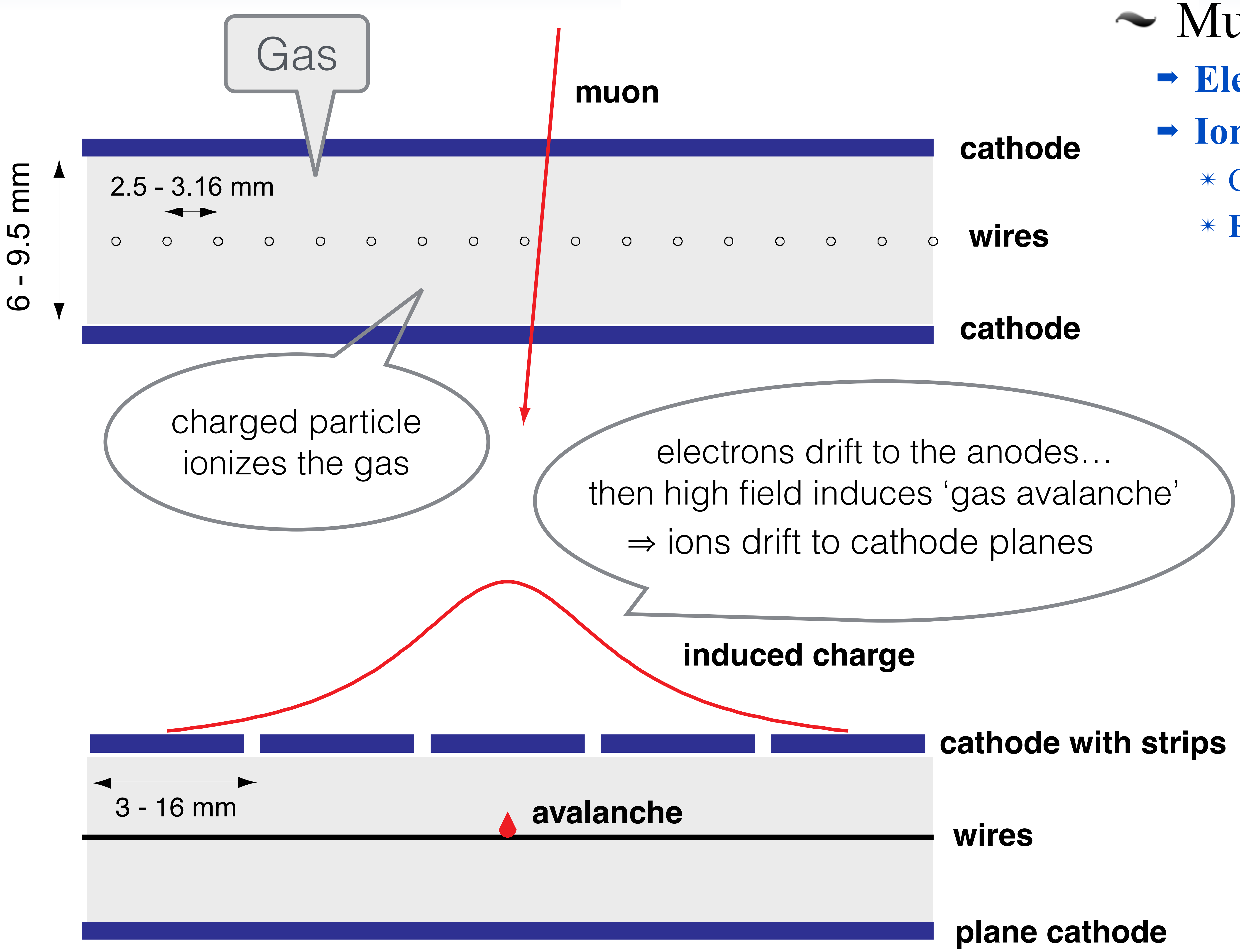
Parameter	ME1/1	ME1/2	ME1/3	ME2/1	ME3/1	ME4/1	ME234/2
HV							
Operating HV [kV]	~3.0			4.1			
HV segments per plane	1 or 2	2	3	3	3	3	5
Overall chamber parameters							
Number of chambers	72	72	72	36	36	36	216
Planes/chamber				6			
φ-coverage, degrees	10°	10°	10°	20°	20°	20°	10°
φ-overlap, strips	5	5	none	5	5	5	5
η-coverage	1.5-2.4	1.2-1.6	0.9-1.1	1.6-2.4	1.75-2.4	1.85-2.4	varies
η-overlap				none			
Length, mm	1680	1800	1900	2065	1845	1665	3380
Width (top), mm	613	1078	1192	1534	1534	1534	1530
Width (bottom), mm	311	740	859	751	835	903	895
Chamber thickness, mm	148			250			
Chamber weight, kg	~60	150	160	190	180	160	276

- Parameters from Muon TDR (1997)
  - http://cds.cern.ch/record/343814

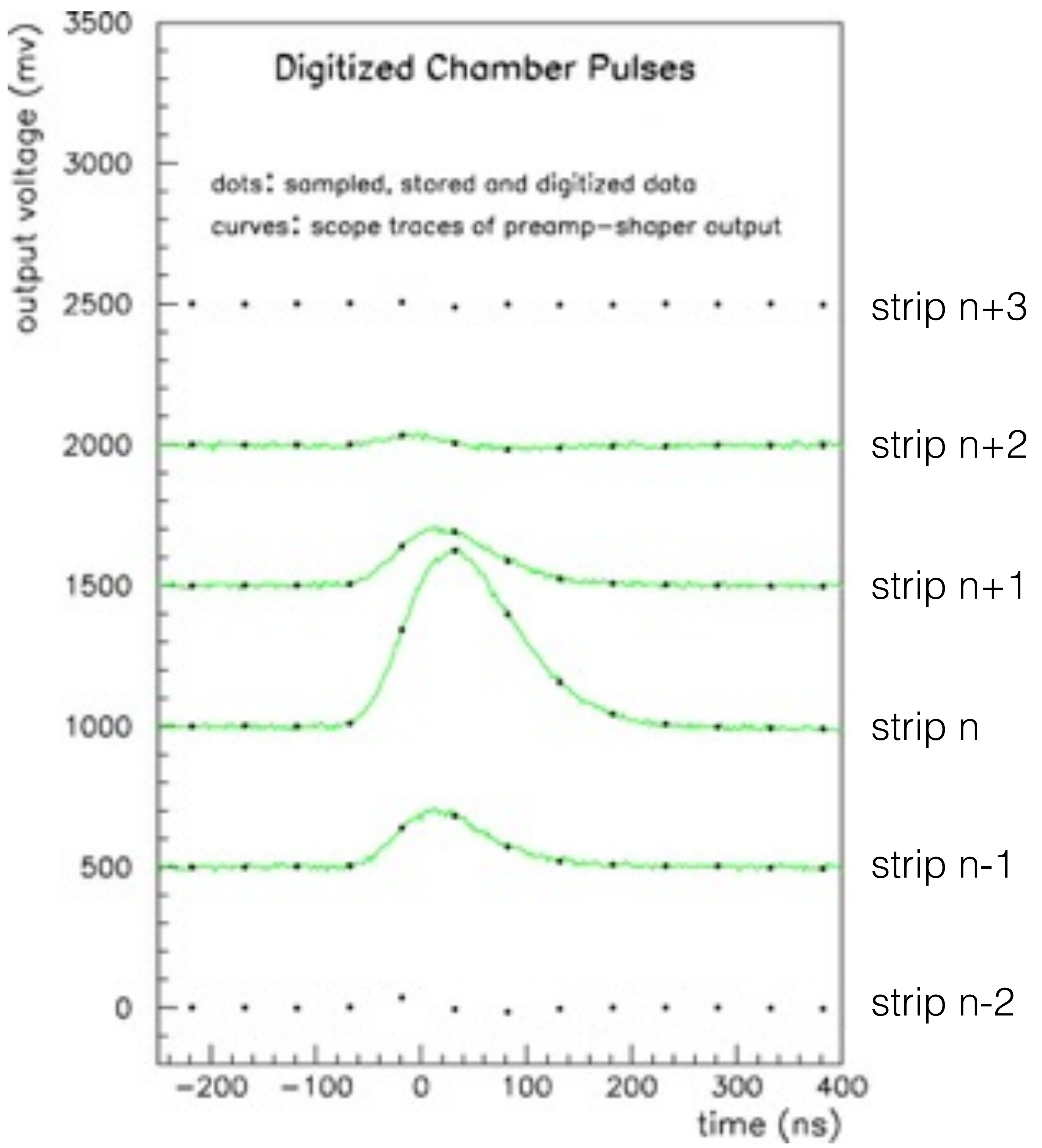
Gas gap: 6 - 9.5 mm
Wire spacing: 2.5 - 3.16 mm
Strip width: 3.15 - 16 mm

Some of these different in final design, eg. HV

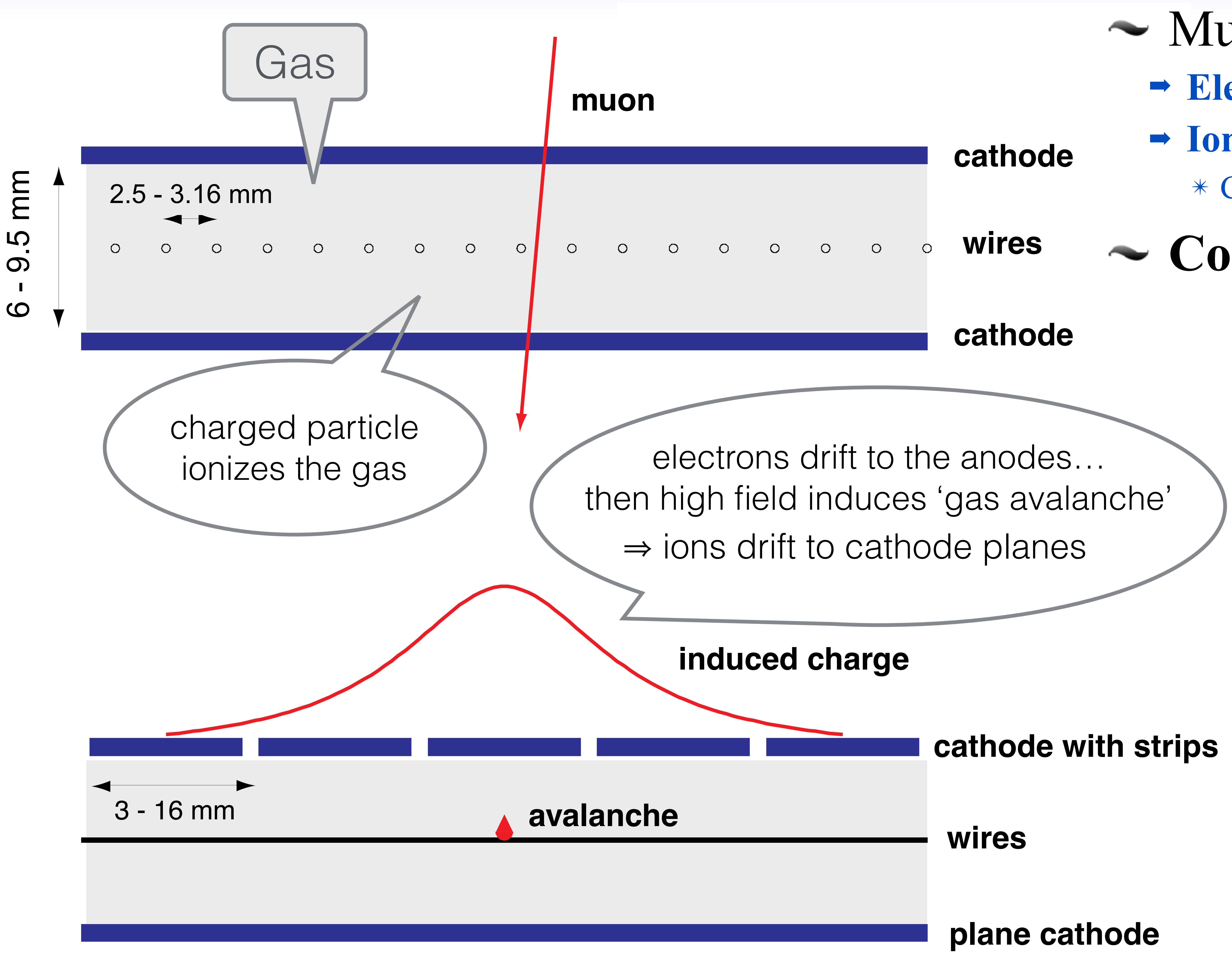
Muon detection by CSC



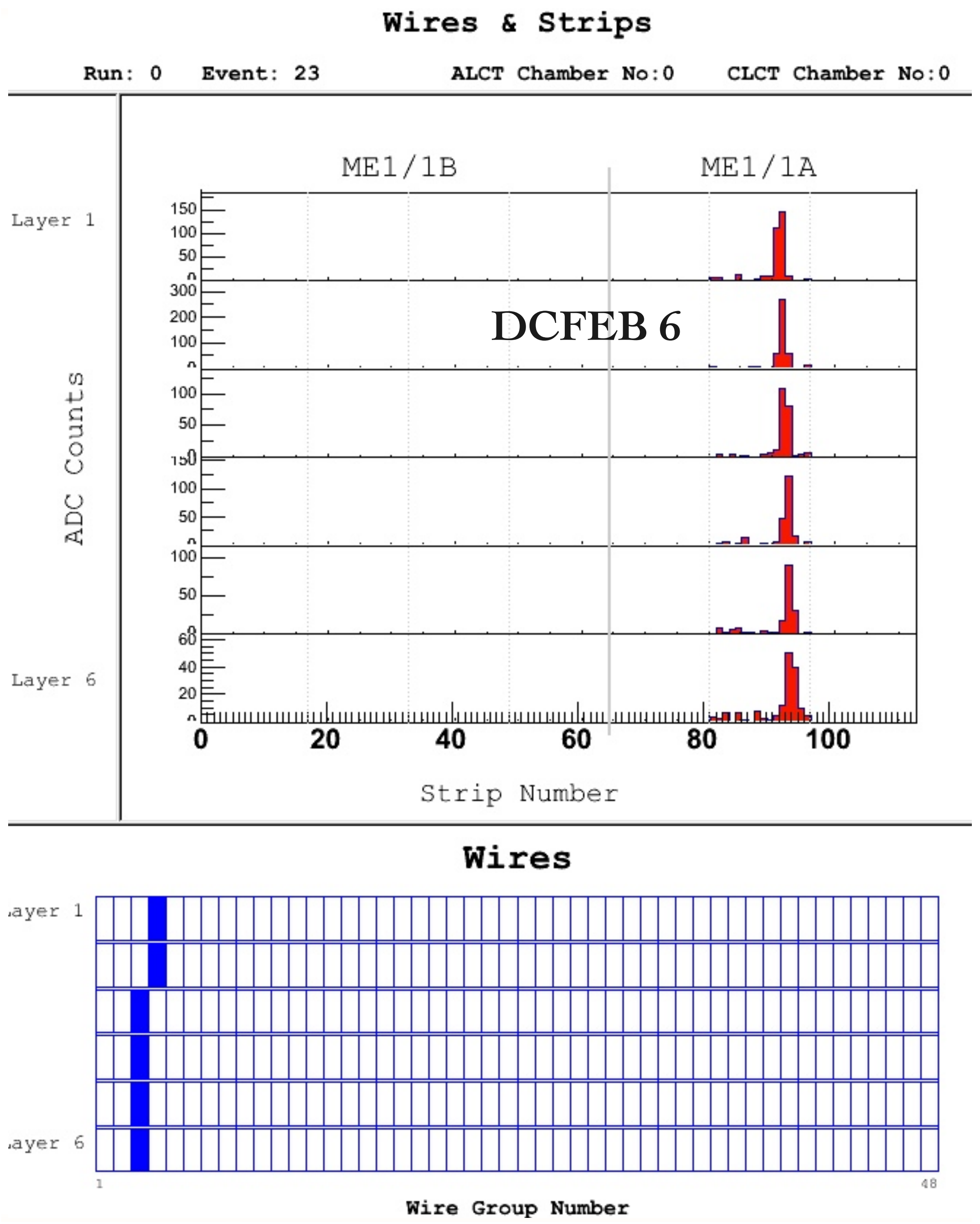
- Muons ionize gas in each gap
  - **Electron** avalanche **drifts quickly to wires** (anodes)
  - **Ions** drift **slowly to strips** (cathodes)
    - Center-of-mass **fit of cathode signal** provides **precision φ** measurement (p_T)
    - **Fit to 8 cathode time samples** provides **precision time measurement**



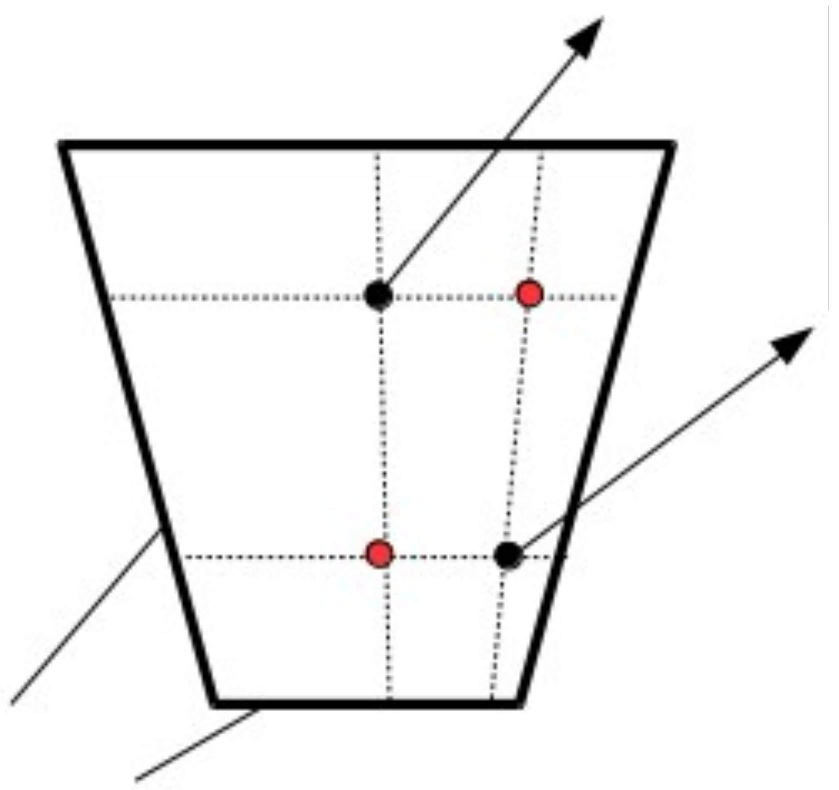
Muon detection by CSC



- Muons ionize gas in each gap
  - **Electron** avalanche **drifts quickly to wires** (anodes)
  - **Ions** drift **slowly to strips** (cathodes)
    - Center-of-mass **fit of cathode signal** provides **precision** φ measurement (p_T)
- **Coincidences** of **anode-cathode** signals form **hits**



More than 1 muon per chamber leads to *ghosts*

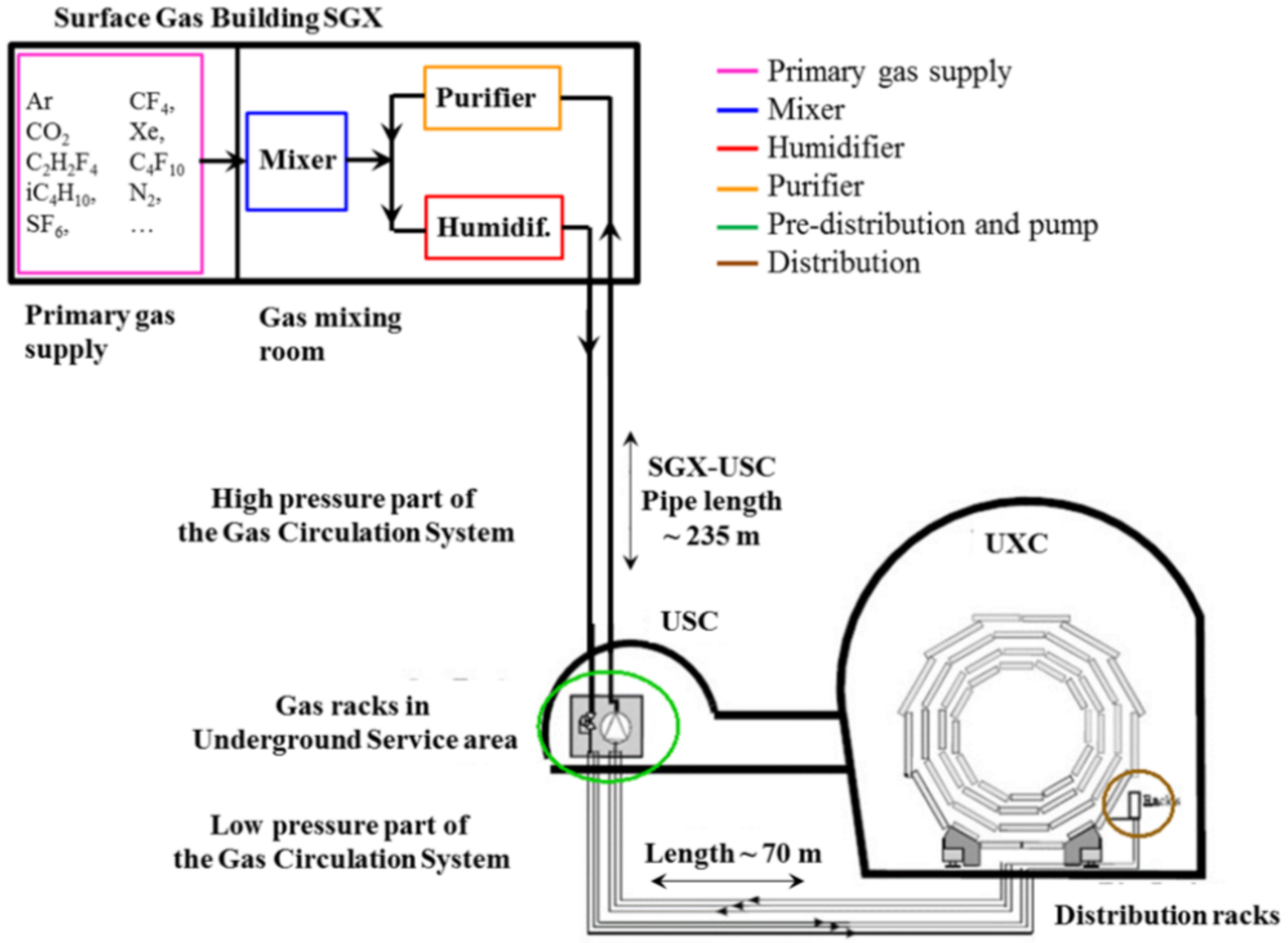


Gas system

- CSCs use **CO_2 (50%) + Ar (40%) + CF_4 (10%)**

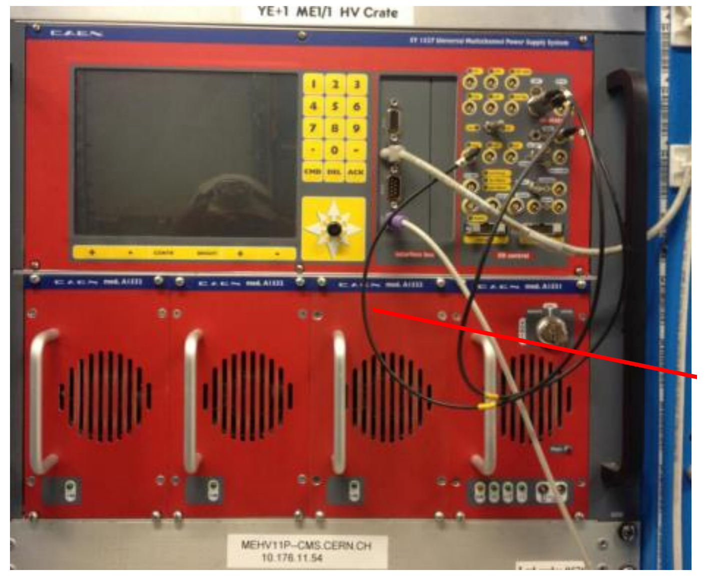
Like all subdetectors, the CSCs obtain gas from the LHC gas system for CMS

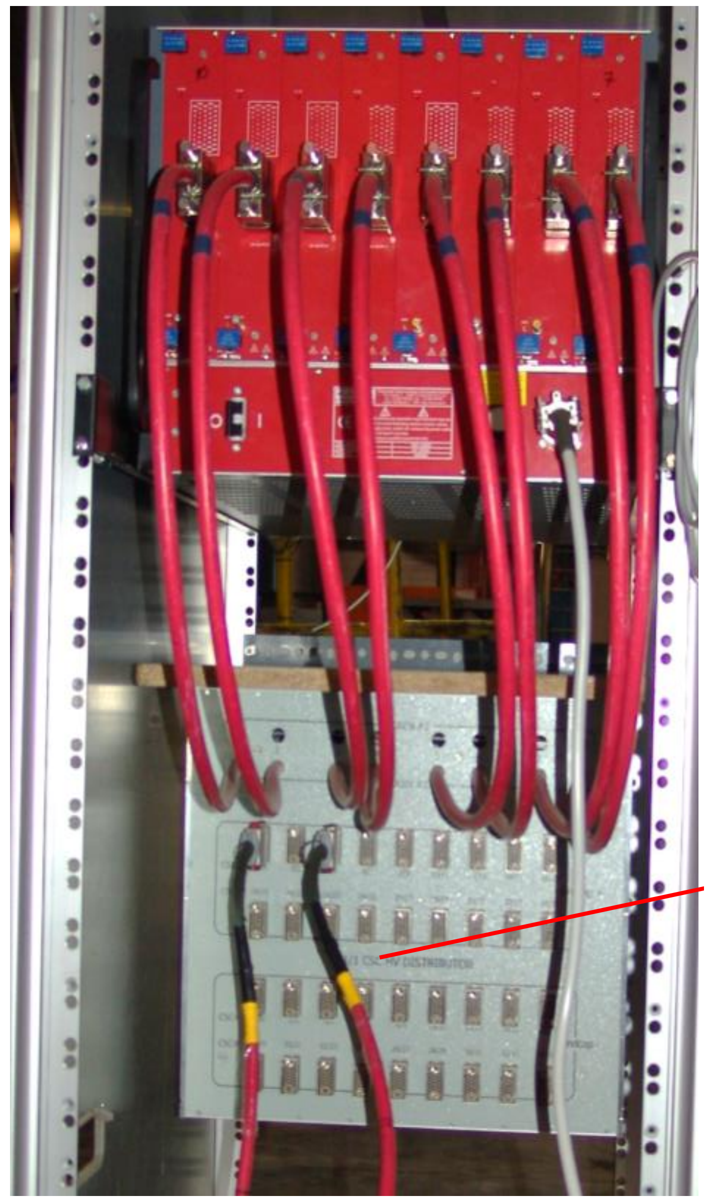
- **Argon produces ionization**
  - More Argon lowers the chambers' operating voltage
    - Increased from 30% to 40% to bring voltage to < 4000 V
- CO_2 is a non-flammable **quenching gas**
  - Helps stabilize operation by minimizing spurious pulses through the absorption of photons
- CF_4 also quenches, but is added mainly because it **prevents aging in wire chambers**
  - Expensive, corrosive greenhouse gas (GWP = 6,500)
  - Studying how to minimize its use or substitute (eco-gas R&D)
    - Proved longevity with 5% CF_4, studying 2%

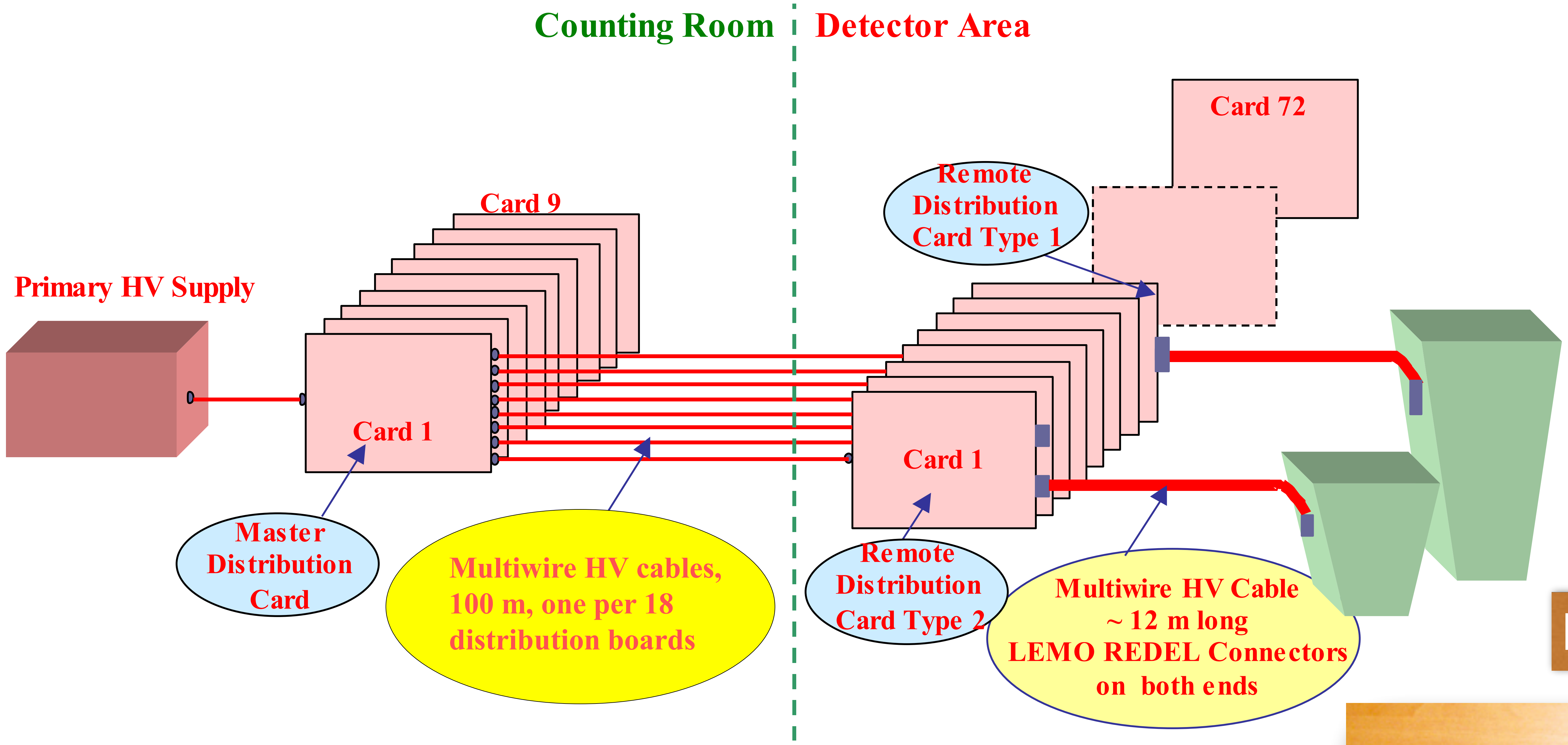


High Voltage system

- **HV system** provides **2.9 kV (ME1/1)** and **3.6 kV (non-ME1/1) to the wires**

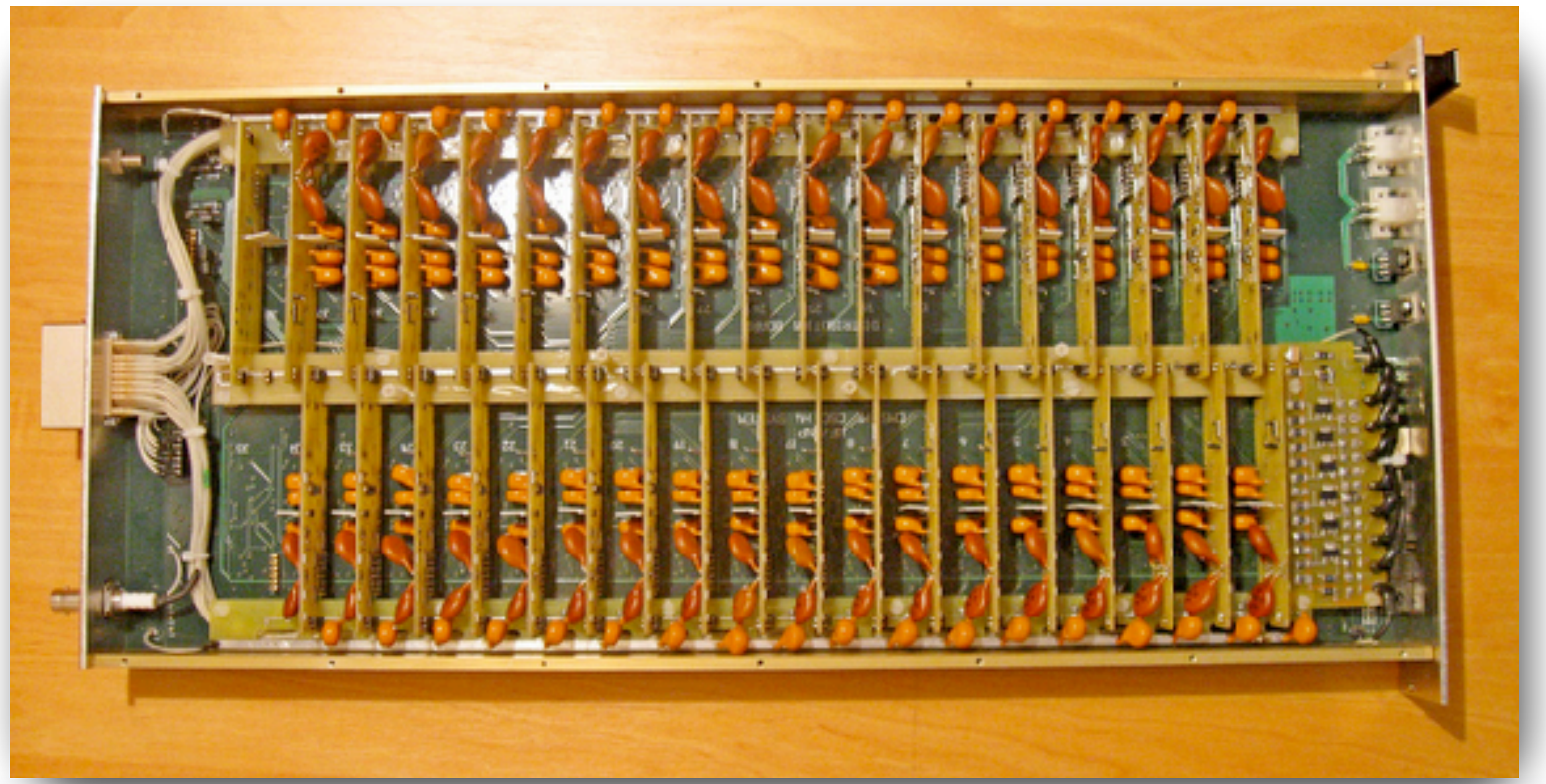






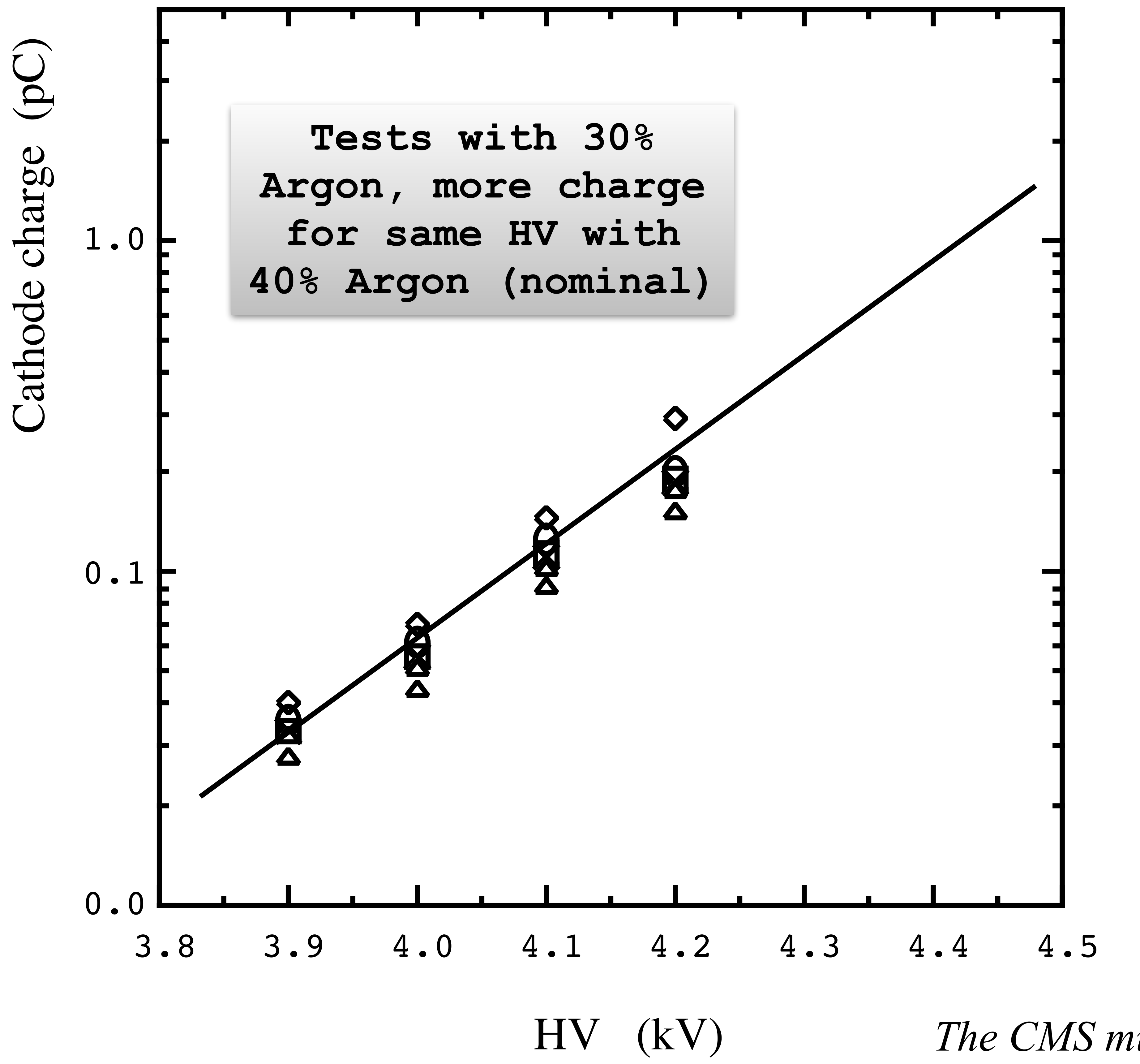
HV power supplies

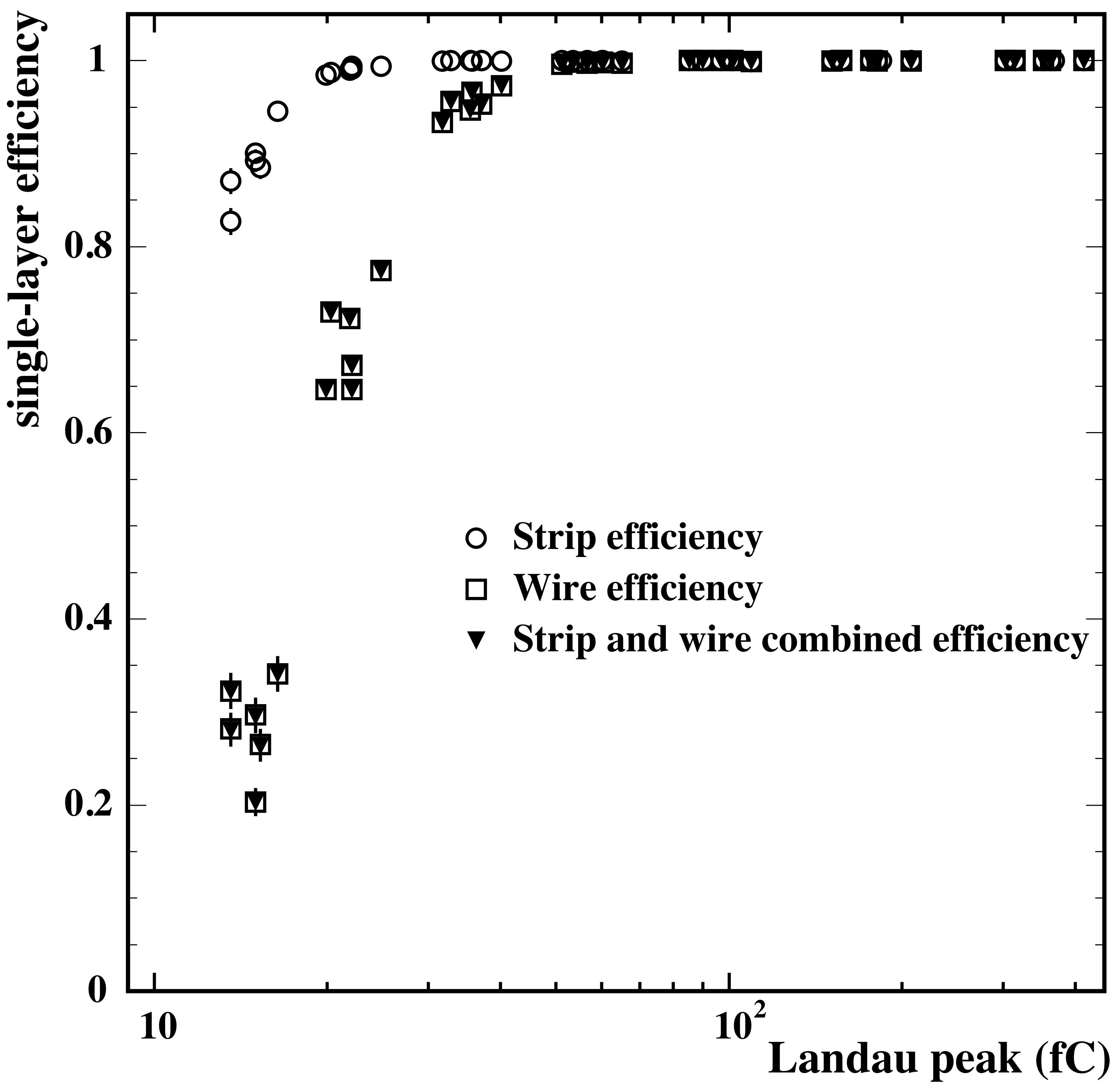
HV Distribution boards



High Voltage system

- **HV system** provides **2.9 kV (ME1/1)** and **3.6 kV (non-ME1/1) to the wires**
  - Amount of **ionization charge depends on bias voltage**
  - We need **enough charge to ensure optimal efficiency**



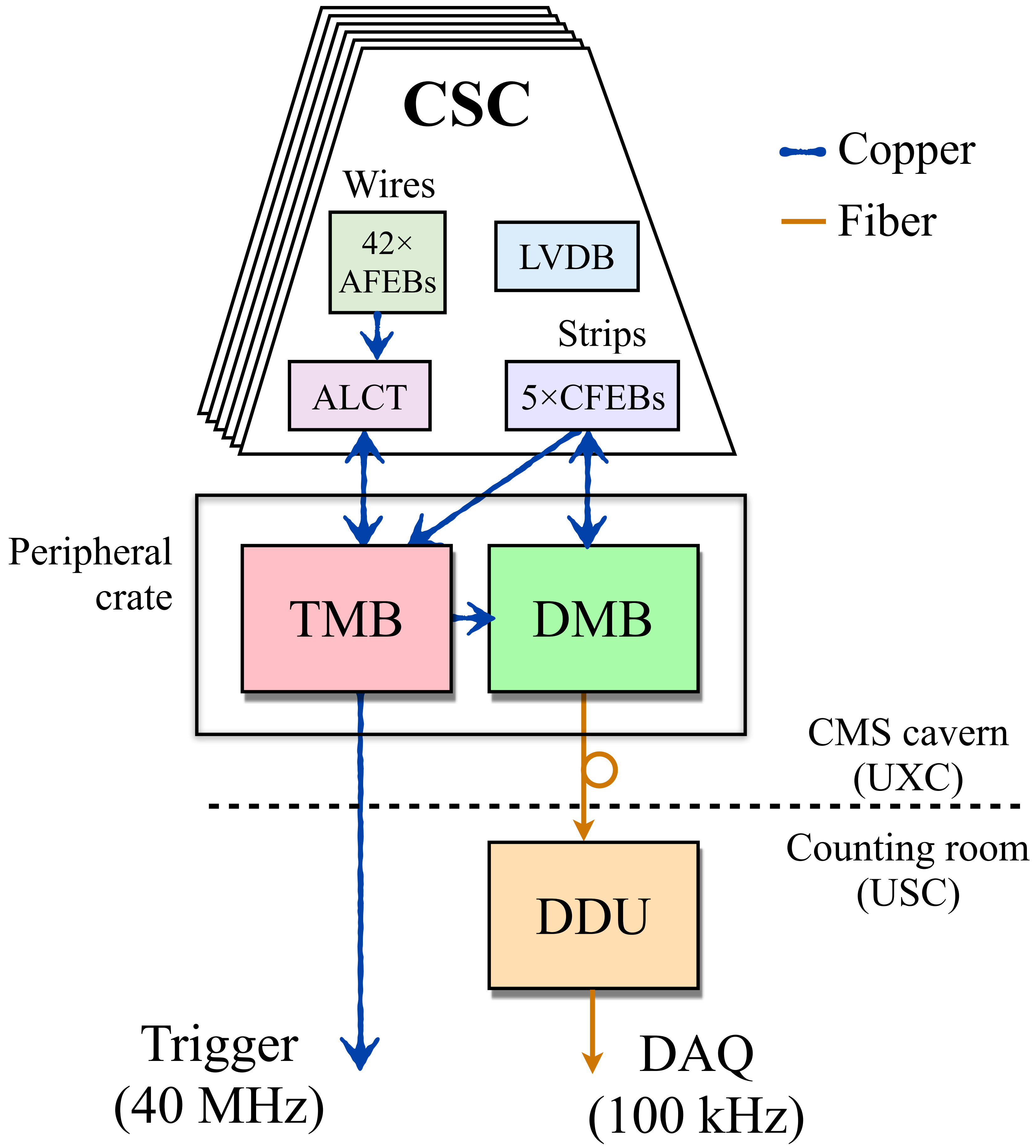


The CMS muon project: TDR, CERN, 1997

We try to **run on plateau but close to the *knee*** so that charge, and thus **aging, is minimized**

Electronics

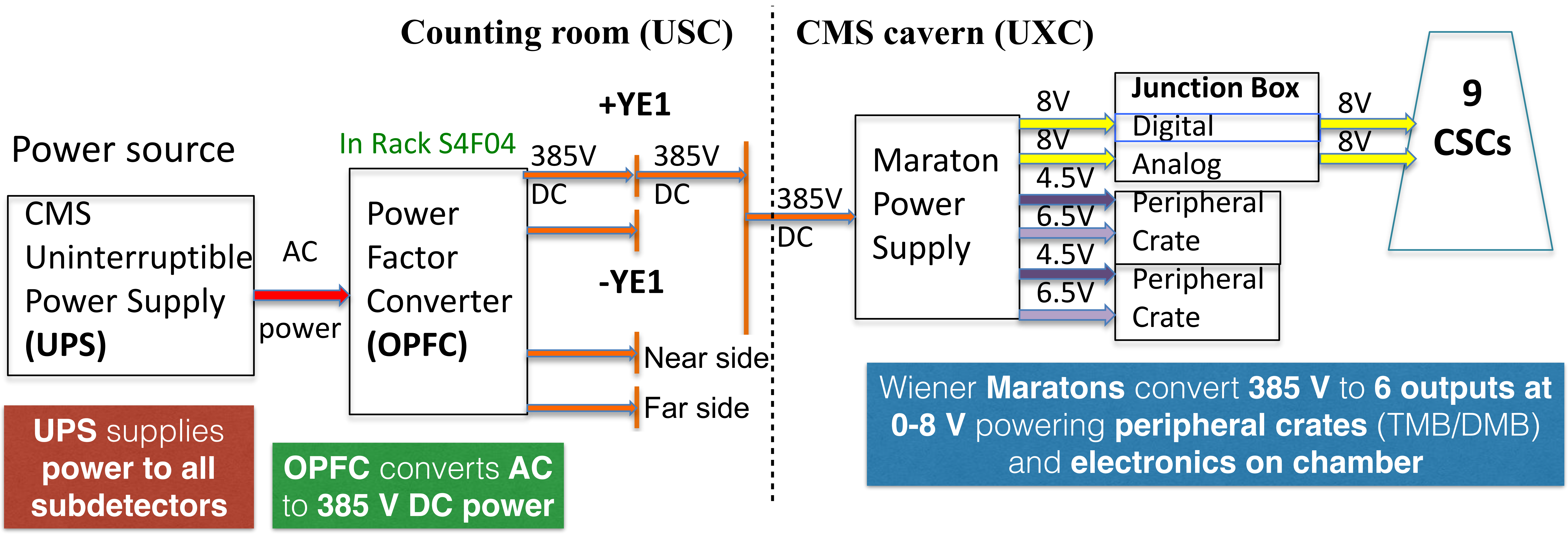
Simplified electronics diagram
for non-ME1/1 chambers



- The electronics read out CSC signals in **two separate paths**
  - **Trigger**: sends **CSC primitives** to the **L1 trigger at 40 MHz**
  - **DAQ**: sends **high-granularity data** to **central DAQ at 100 kHz** (L1A rate)
- **Most** of the day-to-day operation **issues** and hardware **limitations are due to the electronics**
  - **Very important** to have a **basic understanding** of the various boards and their interconnections, as well as the data structure, **to contribute to CSCs**
- In depth discussion in next lecture
  - Present electronics
  - Phase-1 upgrade in LS1 (2013-2014)
  - Phase-2 upgrade in LS2 (2019-2020) and LS3 (2024-2025)

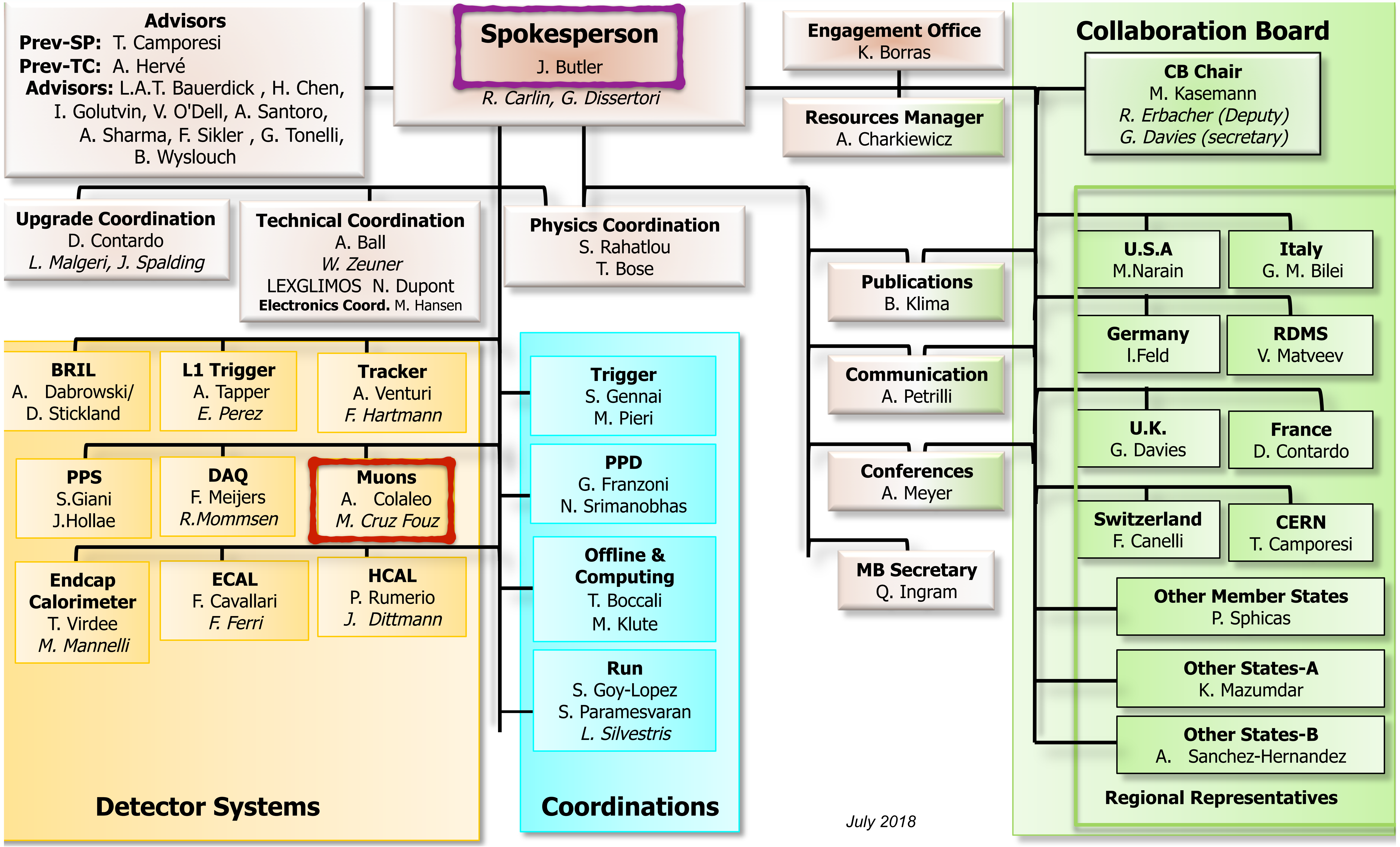
Low Voltage system

- LV system supplies power to electronics in peripheral crates (TMB/DMB) and on chamber
  - Key boards are **Maraton** (MAgnetic and RAdiation TOleraNt) **power supplies**
  - LV parameters monitored by the CANBus system



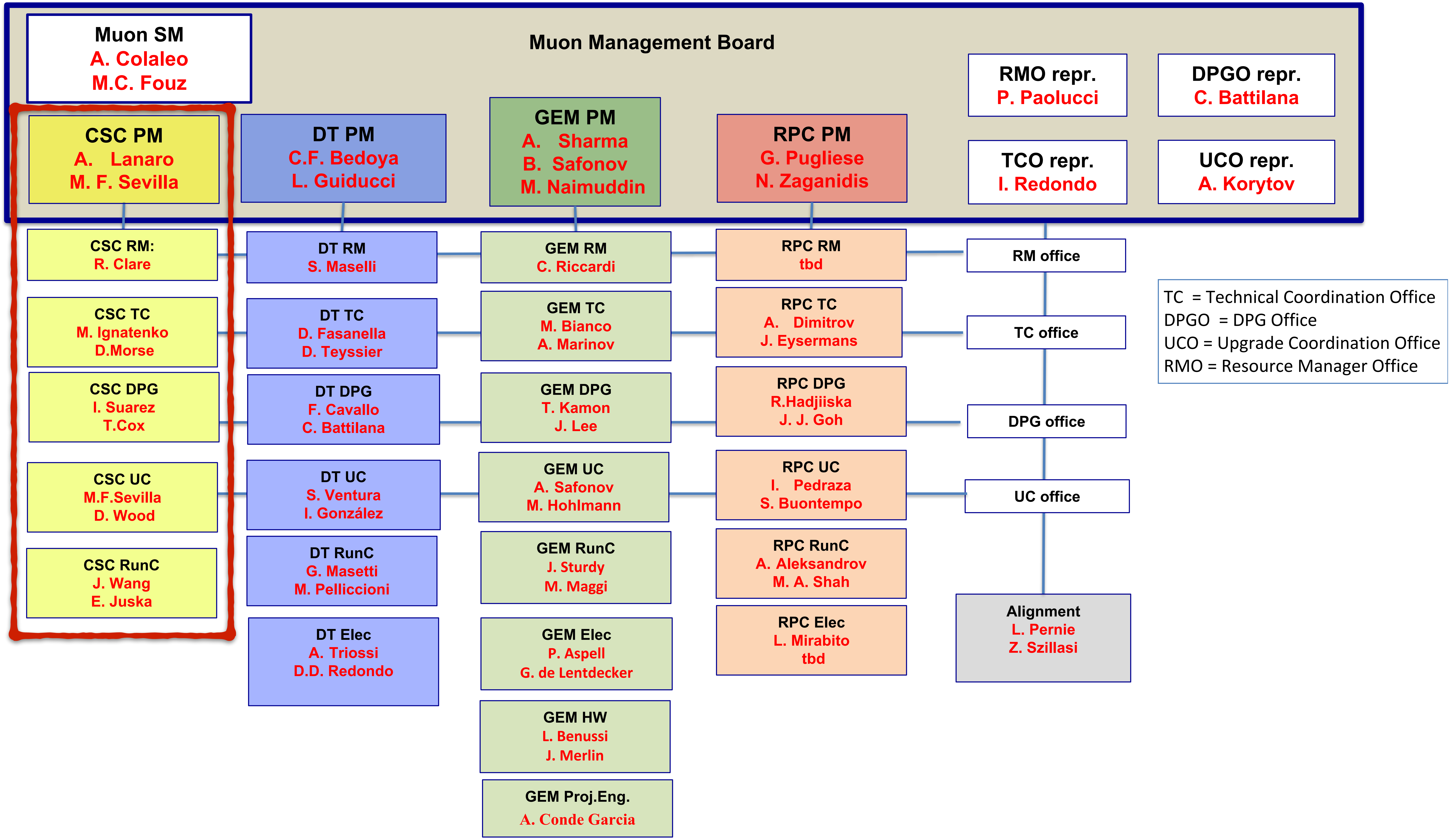
CSC group structure

CMS organization



- **Joel Butler is the spokesperson (*CEO*)**
  - Roberto Carlin incoming
- L1 managers under him
  - **Muon: Anna Colaleo**
  - **Physics: Shahram Rahatlou, Tulika Bose**
  - Upgrade: Didier Contardo
- PAGs and POGs are L2
  - SUS, EXO, HIG, etc
  - MUO, EGM, TAU, etc

Muon organization



- **Anna Colaleo is the Muon manager**
  - María de la Cruz Fouz is deputy
- Four muon subsystems (L2)
  - **CSC: Armando Lanaro**
  - DT: Cristina Bedoya
  - RPC: Gabriella Pugliese
  - GEM: Archana Sharma
- Four coordination offices
  - **Upgrade:** Andrey Korytov
  - **Technical**: Ignacio Redondo
  - **DPG**: Carlo Battilana
  - **Resources**: Pierluigi Paolucci

CSC upgrade organization

<u>Other names not in this chart</u>

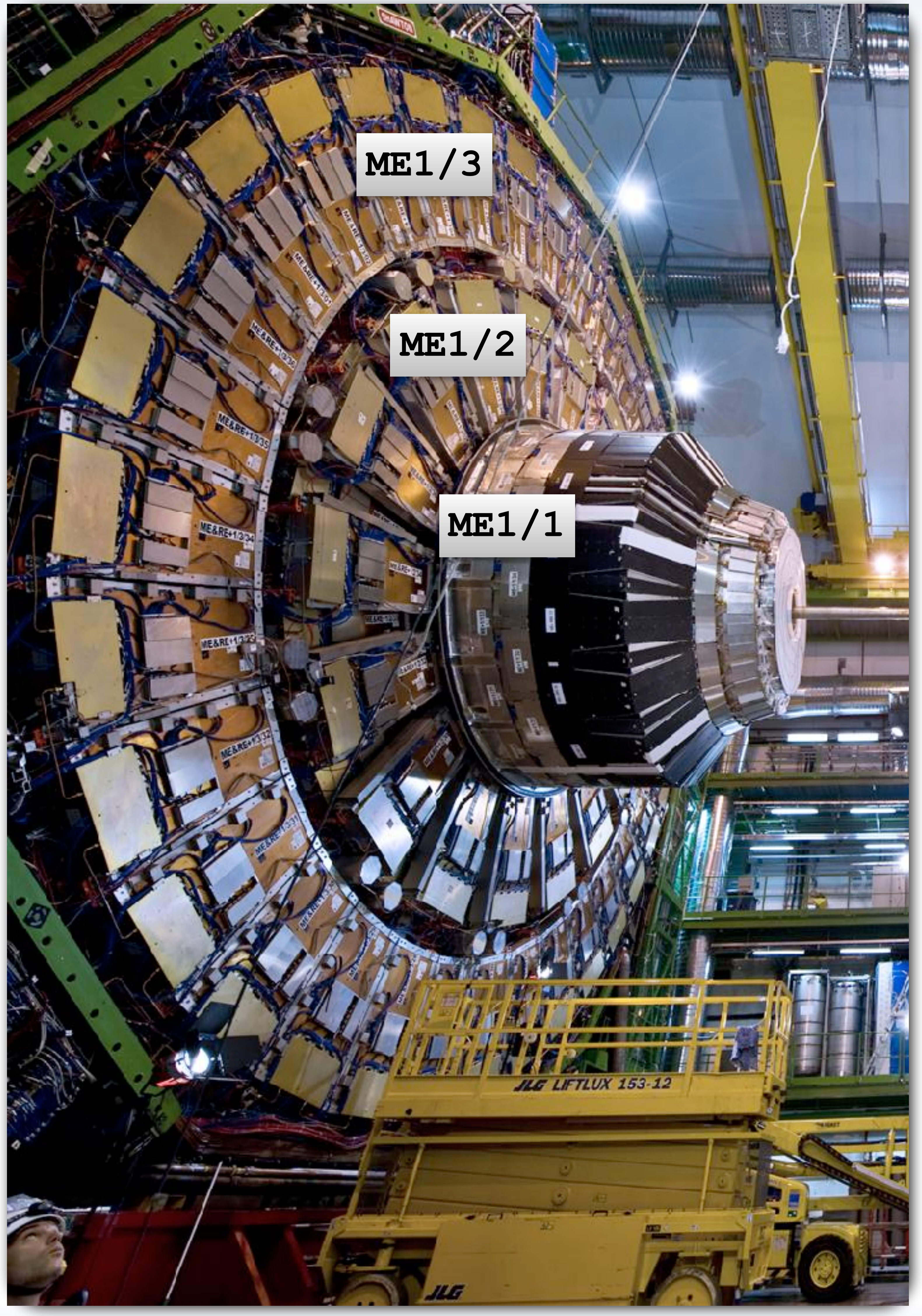
Karoly Banisz, Jinghua Liu: software
Ben Bylsma, Andrew Peck, Jason Gilmore: engineers
Jay Hauser, Dick Loveless: past CSC project managers

CSC project management
A. Lanaro (Wisconsin)
Deputy: M. Franco Sevilla (UC Santa Barbara)

CSC institutional board
IB chair: R. Erbacher (UC Davis)

- **Resource management** — R. Clare (UC Riverside)
- **Detector performance** — I. Suárez Silva (UC Santa Barbara); *Deputy*: T. Cox (UC Davis)
- **Upgrade coordination** — M. Franco Sevilla (UC Santa Barbara); *Deputy*: D. Wood (Northeastern)
  - **Installation/mechanics** — A. Lanaro (Wisconsin)
  - **CSC/GEM** — P. Karchin (Wayne State)
  - **ALCT** — J. Hauser (UCLA)
  - **ODMB** — S. Durkin (Ohio State)
  - **DCFEB** — S. Durkin (Ohio State)
  - **OTMB** — A. Safonov (Texas A&M)
  - **High voltage** — A. Vorobyev (PNPI), G. Mitselmakher (Florida)
  - **Optical fibers** — D. Wood (Northeastern)
  - **Low voltage** — A. Lanaro (Wisconsin)
  - **FED** — A. Safonov (Texas A&M)
  - **LVDB** — V. Karjavine (RDMS)
  - **Upgrade simulation** — T. Cox (UC Davis)
  - **Aging/gas R&D** — A. Korytov (Florida)
- **Technical coordination** — M. Ignatenko (UCLA); *Deputy*: D. Morse (Northeastern)
- **Run coordination** — J. Wang (Florida); *Deputy*: E. Juska (Texas A&M)

Summary

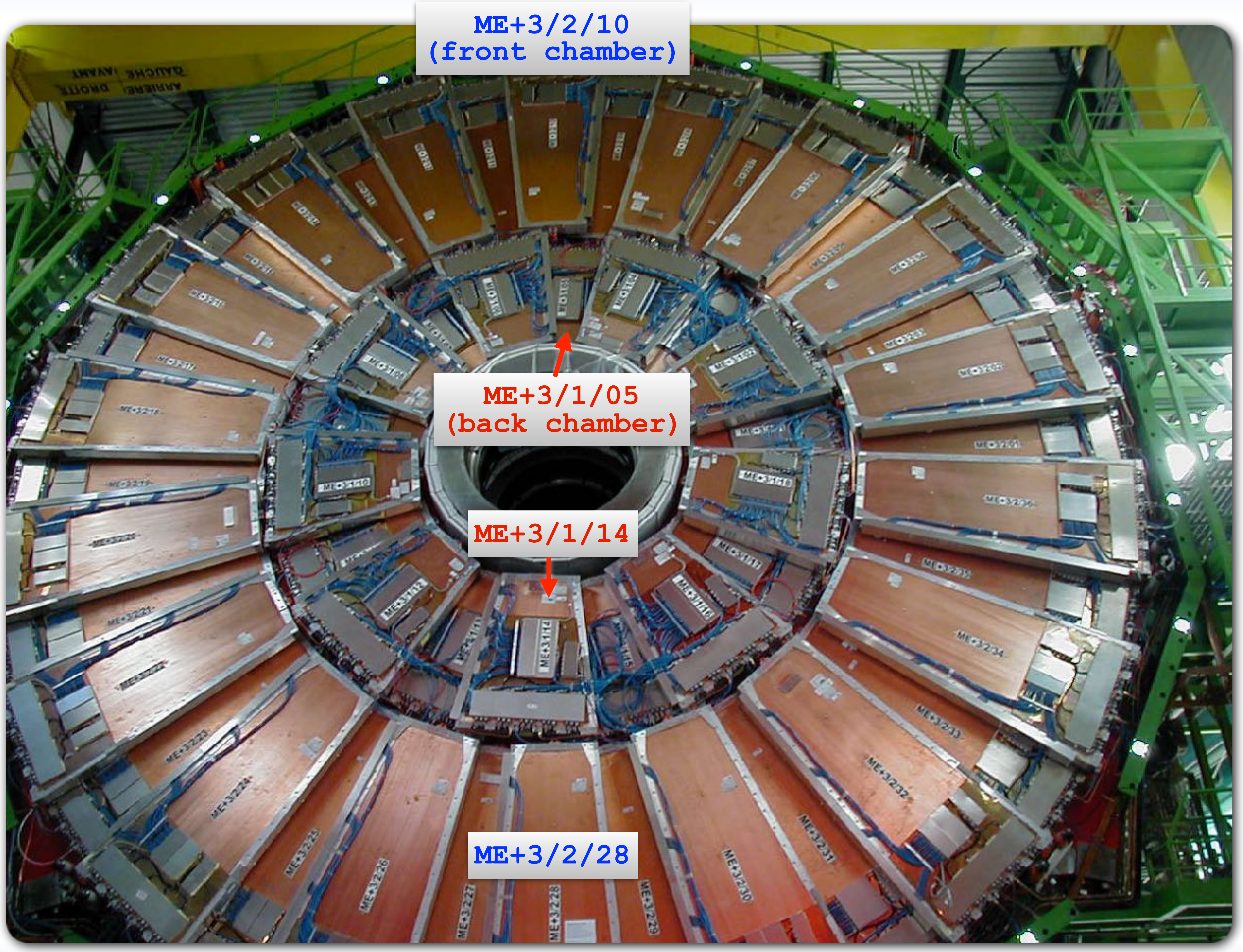


- Slides provide a brief overview of CSC system
  - Comparison to other muon subsystems in CMS
  - Chamber nomenclature
  - Chamber parameters
  - Gas, HV, LV systems
  - Brief overview of electronics
  - CSC group structure

- Useful links
  - **CSC 101 workshop**: https://indico.cern.ch/event/522500/
  - **CSC twiki**: https://twiki.cern.ch/twiki/bin/view/CMS/MuonCSC
  - **CSC hypernews**: https://hypernews.cern.ch/HyperNews/CMS/get/csc-ops.html
  - **Muon TDR (1997)**: http://cds.cern.ch/record/343814
  - **Muon phase-2 upgrade TDR (2017)**: https://cds.cern.ch/record/2283189

Back-up

Extended CSC nomenclature



Muon Endcap plus/minus endcap

ME+2/1/01

Station Ring Chamber

- **Quiz answers from slide 14**
  - How many chambers in ME-2? **54**
  - How many chambers in ME3/1? **36**
  - How many chambers in ME1? **216**
  - How many CSCs in total? **540**